Chapter 6

Motion Economy and Work Design

6 Introduction

Motion economy and work design are crucial aspects of industrial engineering that aim to enhance productivity, reduce worker fatigue, and improve overall efficiency. This chapter explores the purpose, advantages, and methodologies of motion economy and work design, focusing on fundamental motion elements and work analysis techniques, such as Gilbreth's 17 Therbligs. We will also delve into principles related to the human body, workplace arrangement, and the design of tooling and equipment, providing examples and illustrations for clarity. Finally, we will discuss the SIMO chart, a vital tool for visualizing and analyzing work processes.

6.1 Purpose and Advantages of Motion Economy and Work Design

The purpose and advantages of motion economy are described below.

Purpose:

1. Enhance Productivity: Optimize worker movements to increase the output.
2. Reduce Fatigue: Minimize unnecessary motions that cause worker fatigue.
3. Improve Safety: Design tasks and tools that prevent injuries.
4. Standardize Work: Create standardized methods to ensure consistency and quality.
5. Optimize Resource Use: Efficiently utilize human and material resources.

Advantages:

1. Increased Efficiency: Streamlined processes lead to faster and more efficient work.
2. Cost Reduction: Lower operational costs due to reduced waste and improved productivity.
3. Enhanced Worker Morale: Improved working conditions and reduced fatigue contribute to higher worker satisfaction.
4. Quality Improvement: Standardized methods lead to consistent and high-quality output.
5. Better Ergonomics: Properly designed workspaces and tools reduce the risk of musculoskeletal disorders.

6.2 Basic Motion Elements and Work Analysis

Any manual task is comprised of work elements, which can be decomposed into basic motion elements. A motion study consists of the analysis of the basic hand, arm, and body movements of workers as they perform manual work or other physical activity. In contrast, work design involves the design of methods and motions used to perform a task, the layout of the workplace and environment, and tooling and equipment. Hence, work design incorporates the design of the entire work system.

6.2.1 Gilbreth's 17 Therbligs:

Frank and Lillian Gilbreth developed a system to categorize basic motion elements, known as Therbligs. “Therbligs” is a play on words, sort of. It is Gilbreth spelled backwards, for the most part. Therbligs are basic motion elements. representing specific actions performed by workers. In addition to the term “therbligs,” the study of basic motion elements is known as “micromotion analysis”. Understanding and analyzing the 17 elements identified by Frank Gilbreth in Table 6.1 helps in identifying inefficiencies and improving work design.

Table 6.1. MTM Symbol and Gilbreth’s 17 Therbligs

MTM Symbol	Therblig No.	Therblig Symbol	Therblig Name	Description
Reach	1	TE	Transport empty	Moving the hand to reach for an object
	2	G	Grasp	Taking hold an object
Move	3	TL	Transport loaded	Moving an object from one place to another with hand and arm
	4	H	Hold	Retaining an object with one hand while the other hand performs an operation on the part
	5	RL	Release load	Releasing control of an object
	6	U	Use	Manipulating a tool or device to perform a function (i.e., using a screwdriver to turn a screw)
	7	PP	Pre-position	Positioning object for a subsequent operation (i.e., lining up a pin next to a hole for insertion into the hole)
Put	8	PP	Position	Positioning object in a specified location
	9	A	Assemble	Joining two or more parts together
	10	DA	Disassemble	Separating joined parts
	11	Sh	Search	Attempting to find an object using eyes or hand
	12	St	Select	Choosing from among several objects in a

				group
	13	Pn	Plan	Deciding on the next action
	14	I	Inspect	Checking or examining the quality of an object
	15	UD	Unavoidable delay	Waiting due to external factors beyond control of the worker (i.e., waiting for machine to end its cycle)
	16	AD	Avoidable delay	Worker waiting due to internal factors under worker control (i.e., opening a wrapper for a candy bar at workstation, checking the lineup of work orders for the shift)
	17	RL	Rest	Taking a break to overcome fatigue during the work cycle or between work cycles

Key:	Effective therbligs
	Ineffective therbligs

Example 1. Motion Economy for a Flashlight Assembly Process

To illustrate the use of a Right-Hand/Left-Hand Chart depicting an example of motion economy, let's consider a simple assembly process of putting together a flashlight. The process involves the following steps:

1. Pick up the flashlight body.
2. Pick up the battery.
3. Insert the battery into the flashlight body.
4. Pick up the flashlight cap.
5. Screw the cap onto the flashlight body.
6. Inspect the assembled flashlight.

Table 6.2 shows a Left-Hand/Right-Hand Chart for the flashlight assembly process described above:

Table 6.2. Example of Left-Hand/Right-Hand Chart for a Flashlight Assembly Process.

Time (sec)	Left Hand Activity	Right Hand Activity
0-2	Reach for battery	Reach for flashlight body
2-4	Grasp battery	Grasp flashlight body
4-6	Move battery to flashlight	Hold flashlight body
6-8	Insert battery	Hold flashlight body
8-10	Reach for flashlight cap	Hold flashlight body
10-12	Grasp flashlight cap	Hold flashlight body
12-14	Move cap to flashlight	Hold flashlight body
14-16	Hold flashlight body	Screw cap onto flashlight
16-18	Hold flashlight body	Screw cap onto flashlight
18-20	Hold flashlight body	Inspect flashlight

This example shows how each hand's activities are coordinated to accomplish the flashlight assembly task and minimize idle time. By analyzing this chart, opportunities to optimize the process can be identified, such as combining movements or redesigning the layout to reduce reaching time.

6.3 Principles of Motion Economy

The principles of motion economy were developed over decades of practical work experience in work design. Guidelines to aid in determining these principles include analyzing the work method, layout of the workplace, and the tools and equipment used. The objective of motion economy is to maximize worker efficiency while minimizing worker fatigue. There are three categories of principles of motion economy: (1) principles related to the human body, (2) principles that apply to the workplace arrangement, and (3) principles related to the design of tooling and equipment. Each principle is discussed below.

6.3.1 Principles Related to the Human Body:

The principles of motion economy regarding the human body should consider the most appropriate methods and motions of the human worker in the performance of a given task.

1. **Use of Both Hands**: Design tasks so both hands can be utilized simultaneously and symmetrically.
2. **Minimize Fatigue**: Use motions that require the least physical effort.
3. **Use Gravity, Whenever Possible**: Motions that use gravity are easier to perform than motions against gravity, such as raising your arms and working overhead.

4. **Natural Movements**: Use natural and smooth movements to reduce strain.
5. **Proper Height and Reach**: Design workstations to keep materials within easy reach and at proper heights.
6. **Preferred Hand**. Work should be designed to favor the preferred hand since it is typically stronger and more dexterous than the other hand.
7. **Minimize eye focus and eye travel**. Eye focus occurs when the eye must adjust to a change in viewing distance (i.e., from 2 ft to 10 ft). Eye travel occurs when the eye must adjust to a line-of-sight change (i.e., from one location to another but the distances from the eyes are about the same).
8. **Classifications of hand and arm movements**. There are five classifications of hand and arm movements shown in Table 6.3, beginning with the lowest classification, finger motions only.

Table 6.3. Classifications of Hand and Arm Motions

Classification	Description
1	Finger motions only
2	Finger and wrist motions
3	Finger, wrist, and forearm motions
4	Finger, wrist, forearm, and upper arm motions
5	Finger, wrist, forearm, upper arm, and shoulder motions

9. **Fully utilize the worker's knees, feet, and legs, when appropriate**. Legs are stronger than the arms. However, feet are not as easy to use as hands. Work methods should be designed to take advantage of the strength in the legs for lifting or pushing tasks. Sometimes foot or knee pedals can be used to facilitate work operations.

Example 2. One-Handed vs. Two-Handed Task Performance

To demonstrate the impact of using one hand versus both hands in performing a task, let's consider an example task: assembling a small electrical component. The study involves two scenarios:

1. Assembling the component using one hand.
2. Assembling the component using both hands simultaneously.

Task Description:

- **Step 1**: Pick up the base of the component.

- **Step 2**: Pick up a screw.
- **Step 3**: Insert the screw into the base.
- **Step 4**: Pick up a screwdriver.
- **Step 5**: Tighten the screw.

Study Setup:

- **Participants**: 10 workers.
- **Measurements**: Time taken to complete the task, error rate, and worker fatigue level.

Solution:

Metric	One-Handed Task (Average)	Two-Handed Task (Average)
Completion Time (sec)	25.4	15.2
Error Rate (per 100 tasks)	8.0	3.0
Fatigue Level (1-10 scale)	6.5	3.2

Completion Time:

- **One-Handed Task**: 25.4 seconds on average.
  - The participant uses one hand to pick up each part sequentially, which increases the time taken for each step.
- **Two-Handed Task**: 15.2 seconds on average.
  - The participant uses both hands simultaneously, reducing the time taken for the task as both hands work in parallel.

Error Rate:

- **One-Handed Task**: 8 errors per 100 tasks.
  - More frequent errors occur due to the increased complexity of handling parts and tools with one hand.
- **Two-Handed Task**: 3 errors per 100 tasks.
  - Using both hands reduces the likelihood of errors as tasks can be more easily managed and controlled.

Fatigue Level:

- **One-Handed Task**: 6.5 on a scale of 1 to 10.
  - Higher fatigue levels are reported due to the increased strain on a single hand and the longer time spent on the task.
- **Two-Handed Task**: 3.2 on a scale of 1 to 10.
  - Lower fatigue levels are reported as the workload is distributed between both hands, reducing strain and the overall time spent on the task.

Comparison of the Two Task Methods

In the above example, we compare procedural differences between one-handed vs. two-handed task performance.

One-Handed Task Performance:

1. Pick up the base with the right hand.
2. Pick up the screw with the right hand.
3. Insert the screw with the right hand.
4. Pick up the screwdriver with the right hand.
5. Tighten the screw with the right hand.

Two-Handed Task Performance:

1. Right hand picks up the base while the left hand picks up the screw.
2. Left hand inserts the screw while the right hand holds the base steady.
3. Right hand picks up the screwdriver while the left hand holds the screw in place.
4. Right hand tightens the screw while the left hand holds the base steady.

6.4 Principles Related to Workplace Arrangement:

The principles of motion economy should consider the design of the workplace – specifically, the layout of the workstation and the arrangement of tools and parts within the workstation. The following are some suggestions.

1. **Fixed Locations**: Place tools and materials should be in fixed locations that are consistent with the natural sequence of work elements in the work cycle to reduce search time.
2. **Minimize Motions**: Arrange the workplace to minimize unnecessary movements.
3. **Accessibility**: Ensure all necessary tools and materials are easily accessible.
4. **Comfortable Environment**: Maintain a comfortable and well-lit workspace.
5. **Gravity Feed Bins or Drop Chutes**: The use of gravity feed bins or gravity drop chutes should be located near the normal work area for quick and convenient retrieval or deposit of parts.

6.4.1 Normal and Maximum Working Areas

Normal and Maximum Working Areas are fundamental concepts in methods and motion study, often used to design workspaces that enhance efficiency and reduce worker fatigue. These areas define the optimal zones within which a worker can comfortably reach and operate tools and materials without excessive strain or movement.

Principles:

- **Normal Working Area**: This is the area within which a worker can reach and perform tasks comfortably with minimal arm and body movement. It usually involves motions made by the forearm while keeping the upper arm relatively still.
- **Maximum Working Area**: This extends beyond the normal working area and includes the maximum reach of a worker. This area may involve full arm extension and body movement, which can lead to increased fatigue and decreased efficiency if used frequently.

Figure 6.1 provides an illustration of the normal and maximum working areas in a workplace:

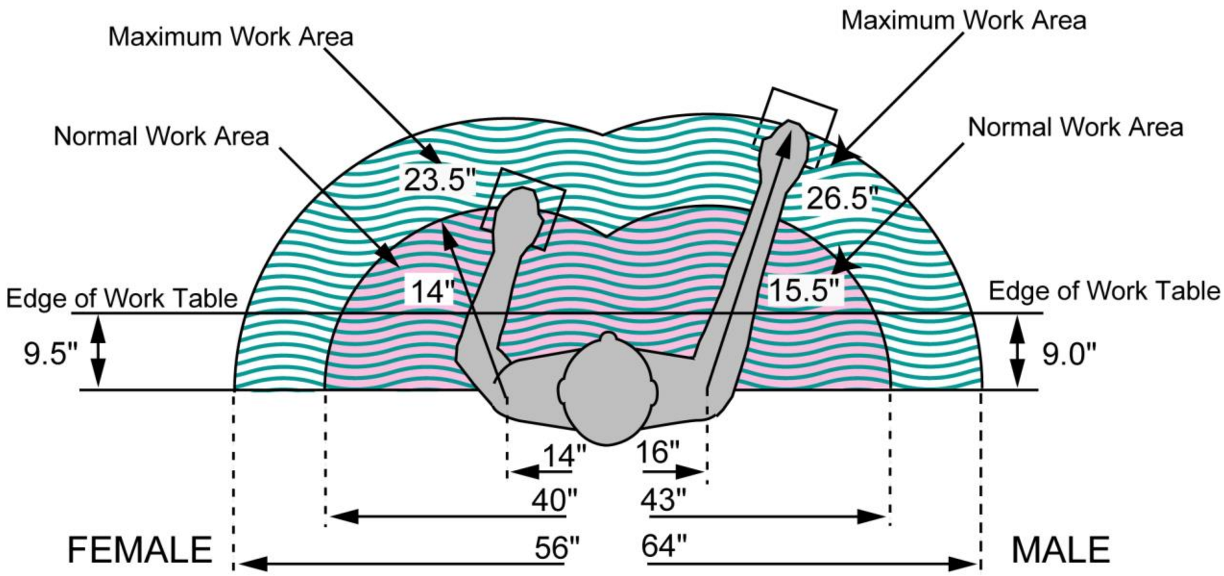

Figure 6.1. Normal and maximum areas in the workplace.

Description:

1. **Normal Working Area**:
   - The shaded area closest to the worker.
   - Defined by the comfortable reach of the forearm while the upper arm remains close to the body.
   - Includes frequently used tools and materials to minimize unnecessary movements and reduce fatigue.
   - The normal working areas is represented by a semi-circle with a radius of about 30-40 cm (12-16 inches) from the worker's shoulder.
2. **Maximum Working Area**:
   - The larger shaded area extends beyond the normal working area.
   - Defined by the full extension of the arm and some body movement.
   - Includes less frequently used tools and materials to avoid frequent reaching and movement.
   - Typically, a semi-circle with a radius of about 60-75 cm (24-30 inches) from the worker's shoulder.

6.4.2 Dimensions of Normal and Maximum Working Areas

The dimensions of normal and maximum working areas can vary based on ergonomic standards and the specific requirements of the workplace. However, general guidelines can be applied to most workstations. Table 6.4 provides typical dimensions for normal and maximum working areas:

Table 6.4. Typical dimensions for Normal and Maximum working areas.

Dimension	Normal Working Area	Maximum Working Area
Vertical Reach (Height)	40-50 cm (16-20 in)	75-90 cm (30-36 in)
Horizontal Reach (Width)	60-80 cm (24-32 in)	120-150 cm (48-60 in)
Radial Distance (from Shoulder)	30-40 cm (12-16 in)	60-75 cm (24-30 in)

1. **Vertical Reach (Height)**:
    - **Normal Working Area**: The vertical space within easy reach when the forearm is bent at the elbow, typically 40-50 cm (16-20 inches) from the work surface.
    - **Maximum Working Area**: The vertical space within maximum reach when the arm is fully extended upwards, typically 75-90 cm (30-36 inches) from the work surface.
2. **Horizontal Reach (Width)**:
    - **Normal Working Area**: The horizontal space within easy reach when the forearm is bent at the elbow, typically 60-80 cm (24-32 inches) across the worker's body.
    - **Maximum Working Area**: The horizontal space within maximum reach when the arm is fully extended side-to-side, typically 120-150 cm (48-60 inches) across the worker's body.
3. **Radial Distance (from Shoulder)**:
    - **Normal Working Area**: The radial distance from the shoulder to the farthest point within easy reach, typically 30-40 cm (12-16 inches).
    - **Maximum Working Area**: The radial distance from the shoulder to the farthest point within maximum reach, typically 60-75 cm (24-30 inches).

Example 3. Assembly Workstation Design

Figure 6.2 depicts an ergonomically designed assembly workstation.

Figure 6.2. An ergonomic assembly workstation.

- **Normal Working Area**:
    - Place essential tools like screwdrivers, pliers, and frequently used small parts within easy reach.
    - Arrange components that are part of the immediate assembly process within this zone.
    - Use an ergonomically designed chair, when feasible.
- **Maximum Working Area**:
    - Store large components, infrequently used tools, and supplies outside the normal working area, but within maximum reach.
    - Items in this area should require minimal movement to access and should not be needed constantly during the task.

Designing workspaces using the concepts of normal and maximum working areas enhances efficiency and reduces worker fatigue. By positioning frequently used tools and materials within the normal working area, unnecessary movements are minimized, leading to more ergonomic and productive work processes. This principle is a cornerstone of methods and motion study, helping to create safer and more efficient industrial environments.

Example 4. Office Work Area

Figure 6.3 depicts an ergonomically designed office work area.

Figure 6.3. An ergonomically designed office work area.

Examples of items that should be included within the normal and maximum working areas of an office workstation include:

- **Normal Working Area**:
    - Items like a keyboard, mouse, frequently used documents, and small office supplies (e.g., pens, notepads) are placed within the normal working area.
    - This area typically spans the immediate desk space directly in front of the worker, ensuring easy access without excessive reaching.
- **Maximum Working Area**:
    - Less frequently used items such as a telephone, reference books, and personal items are placed within the maximum working area.
    - This area includes the peripheral desk space and nearby shelves or drawers, allowing access with a bit more effort but not frequently disturbing the worker’s primary tasks.

Hence, defining and adhering to the dimensions of normal and maximum working areas helps create ergonomic workstations that improve efficiency and reduce fatigue. By strategically placing tools and materials within these zones, workers can perform their tasks more comfortably and effectively, thereby becoming more productive and less fatigued.

6.4.3 Good vs. Bad Workplace Arrangements

Examples of good and bad workplace arrangements are provided for illustrative purposes.

6.4.3.1 Good Workplace Arrangement

A good workplace arrangement follows the principles of motion economy, ensuring that frequently used tools and materials are within the normal working area to minimize unnecessary movements and reduce worker fatigue. Figure 6.4 provides an example of a good workplace arrangement.

Figure 6.4. A good workplace arrangement of a clean automotive assembly line.

6.4.3.2 Features of a Good Workplace Arrangement

- **Tools and materials within easy reach:** Frequently used items are placed within the normal working area (30-40 cm radial distance from the shoulder).
- **Clear and clutter-free workspace:** The work area is organized, reducing the need for searching and unnecessary movements.
- **Proper lighting and ergonomics:** Adequate lighting and ergonomically designed equipment to enhance comfort and efficiency.

6.4.3.3 Key Elements in a Good Workplace Arrangement

1. Frequently used tools (e.g., screwdriver, pliers) are within the normal working area.
2. Infrequently used tools (e.g., hammer) are within the maximum working area, but still accessible without excessive movement.
3. Work surface is clear and organized, reducing clutter.
4. Proper lighting ensures the worker can see the task clearly without straining.
5. Ergonomic chair and workstation to maintain good posture, when applicable.

6.4.4 Bad Workplace Arrangement

A bad workplace arrangement ignores the principles of motion economy, leading to inefficient work processes, increased fatigue, and a higher risk of injury. Figure 6.5 provides an example of a bad workplace arrangement.

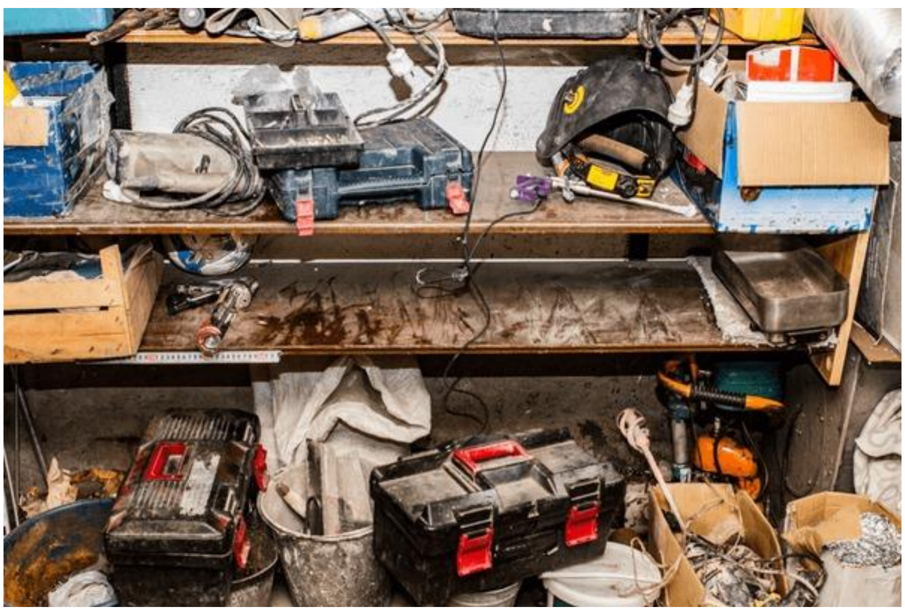

Figure 6.5. A bad workplace arrangement of a workstation.

6.4.4.1 Features of a Bad Workplace Arrangement

- **Tools and materials out of reach:** Frequently used items are placed outside the normal working area, requiring excessive reaching.
- **Cluttered workspace:** The work area is disorganized, increasing the time spent searching for tools and materials.

- **Poor lighting and ergonomics:** Inadequate lighting and poorly designed equipment contribute to discomfort and inefficiency.

6.4.4.2 Key Elements in the Bad Workplace Arrangement

1. Frequently used tools are placed far from the worker, outside the normal working area.
2. Infrequently used tools are mixed with frequently used ones, leading to confusion and unnecessary movement.
3. Work surface is cluttered, causing the worker to spend time searching for tools and materials.
4. Poor lighting makes it difficult to see the task, causing eye strain.
5. Non-ergonomic chair and workstation leading to poor posture and discomfort.

6.4.4.3 Principles Related to the Design of Tooling and Equipment:

The principles of motion economy should consider the design of special tools or controls on equipment that are used in the workplace. The following are some suggestions.

1. **Ergonomic Tools**: Design tools that fit comfortably in the hand and reduce effort.
2. **Standardization**: Use standardized tools and equipment to reduce variation.
3. **Workholder devices**. Use mechanical workholders with fast-acting clamps, whenever possible, to free both hands to work on a part.
4. **Multi-purpose Tools**: Design tools that can perform multiple functions to reduce the number of tools needed (i.e., claw hammer, pencil with eraser, Swiss army knife).
5. **Use Foot or Knee Devices**. The use of foot-pedal (i.e., sewing machine) or knee-pedal (i.e., rotating a cylinder on a machine during a setup) controls can free the hands to work simultaneously on an activity.
6. **Automation**: Incorporate automation to perform repetitive tasks.

Example 5. Ergonomic Tool

Consider a screwdriver designed with an ergonomic handle. The handle is shaped to fit comfortably in the hand, reducing strain on the wrist. Figure 6.6 shows a ratchet screwdriver that features a ratcheting mechanism, allowing the user to tighten or loosen screws without repositioning their hand, minimizing repetitive motions, and increasing efficiency.

Figure 6.6. A ratchet screwdriver.

6.5 Work Analysis with SIMO Chart

Motion studies use graphical simulations of motion and may include visual properties such as different lighting effects and camera perspectives into a motion study. These graphical simulations animate prescribed motions for workers.

6.5.1 SIMO (Simultaneous Motion) Chart

The SIMO (Simultaneous Motion) chart is a tool used to analyze and document the simultaneous movements of a worker’s hands (and sometimes other body parts) during a task. By identifying periods of idle time and inefficiencies, the chart helps industrial engineers redesign tasks to optimize productivity and reduce worker fatigue. It helps identify inefficiencies and opportunities for improvement by visually representing the sequence and timing of motions.

6.5.2 Steps to Create a SIMO Chart:

1. **Observe and Record**: Observe the worker performing the task and record each motion of both hands.
2. **Classify Motions**: Classify each motion using Therbligs.
3. **Construct the Chart**: Create a two-column chart representing the left and right hands and plot the motions against a time scale.
4. **Analyze**: Identify periods where one hand is idle or performing non-value-added motions.
5. **Optimize**: Redesign the task to synchronize hand movements, eliminate unnecessary motions, and balance the workload between both hands.

Example 6. SIMO Chart

Below is an example of a SIMO chart for assembling a small electrical component.

The task involves assembling a small electrical component with the following steps:

1. Pick up the component base.
2. Pick up a screw.
3. Insert the screw into the base.
4. Pick up a screwdriver.
5. Tighten the screw.

An example of the SIMO chart for the small electrical component assembly process is shown in Table 6.4.

Table 6.4. SIMO Chart for Assembly Process

Time (sec)	Left-Hand Activity	Right-Hand Activity
0-26.	Idle	Reach for component base
2-4	Idle	Grasp component base
4-6	Reach for screw	Hold component base
6-8	Grasp screw	Hold component base
8-10	Move screw to base	Position component base
10-12	Insert screw into base	Hold component base steady
12-14	Hold component and screw	Reach for screwdriver
14-16	Hold component and screw	Grasp screwdriver
16-18	Hold component and screw	Position screwdriver onto screw
18-20	Hold component steady	Tighten screw
20-22	Hold component steady	Tighten screw
22-24	Hold component steady	Release screwdriver
24-26	Hold component steady	Inspect assembled component

Analysis

- **Efficiency**: The chart shows that the left hand is idle during certain periods. This indicates potential inefficiencies that can be addressed by re-designing the task to utilize both hands more effectively.

- **Improvements**: Introducing parallel actions, such as having the left hand prepare the next screw while the right hand tightens the current one, can reduce idle time and improve overall task efficiency.

A SIMO chart is an effective tool for visualizing and analyzing the simultaneous motions of a worker's hands during a task, by analyzing and improving the assembly process of small electrical components in this example. By identifying periods of idle time and inefficiencies, the chart helps industrial engineers redesign tasks to optimize productivity and reduce worker fatigue.

6.6 Summary

Motion economy and work design are essential for optimizing productivity, enhancing worker safety and comfort, and improving overall operational efficiency. By understanding basic motion elements, applying principles related to the human body, workplace arrangement, and tooling design, and utilizing tools like the SIMO chart, industrial engineers can create more efficient and effective work systems. Proper workplace arrangement is crucial for enhancing productivity, reducing fatigue, and improving overall worker satisfaction. By placing frequently used tools and materials within the normal working area, maintaining a clear and organized workspace, and ensuring proper ergonomics and lighting, workplaces can significantly improve worker productivity, efficiency, and safety. These illustrations are highlighted in the stark differences between good and bad workplace arrangements, underscoring the importance of thoughtful design in work environments. This chapter provides a foundation for these concepts, offering practical insights and examples to guide the application of motion economy and work design principles in various industrial settings.

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