Enhancing Efficiency and Cost Effectiveness in a Mobile Assembly Plant Through the Implementation of Lean Six Sigma, Kaizen, Kanban and Industry 4.0

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A thesis submitted to the National University of Sciences and Technology, Islamabad,

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DEDICATION

Dedicated to my family, friends, and teacher, whose unwavering support, cooperation, and love have been instrumental in helping me reach this significant achievement.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AI	Artificial Intelligence
IOT	Internet of Things
JIT	Just In Time
SALBP	Simple Assembly Line Balancing Problem
GALBP	General Assembly Line Balancing Problem
ALB	Assembly Line Balancing
TALB	Two Sided Assembly Line Balancing
MMALBP	Mixed Model Assembly Line Balancing Problem
STALBP	Sided Assembly Line Balancing Problem
CPMIP	Constrained Piecewise Linear Mixed Integer Program
SA	Simulated Annealing
ACO	Ant Colony Optimization
GA	Genetic Algorithm
RPWR	Ranked Positional Weight Rule
PTALBP	Parallel Two Sided Assembly Line Balancing Problem
ALBP	Assembly Line Balancing Problem
MMAL	Mixed Model Assembly Line
MALBP	Manned Assembly Line Balancing Problem
TCP	Total Covering Problem
PCP	Partial Covering Problem
SCP	Set Covering Problem
ACLP	Anti-Covering Location Problem

GVC	Global Value Chain
GPN	Global Production Networks
DES	Discrete Event Simulation
LOT	Longest Operating Time
RPWT	Ranked Positional Weight Technique
CPM	Critical Path Method
ICT	Information and Communication Technologies
TC	Technological Capability
GALBPS	General Assembly Line Balancing Problem with Setups
IFFR	Iterative First Fit Rule
MIP	Mixed Integer Programming
GALBPS	General Assembly Line Balancing Problem with Setups Type II
RTI	Radio Testing Input
TP	Touch Panel
QC	Quality Control
AGVs	Automated Guided Vehicles
ASP	Assembly Sequence Planning
MFT	Most Following Tasks
SOT	Shortest Operating Time
FFT	Fewest Following Tasks
UPPH	Units Per Person Hour
MES	Manufacturing Execution System
MB	Motherboard
RQC	Reliability, Quality, and Compliance

CT	Cycle Time
MTNS	Minimum Theoretical Number of Stations
ANS	Actual Number of Stations
TA	Time Allocated (Seconds/Cycle)
TBA	Task Breakdown Analysis
TDB	Task Detail Breakdown
PCR	Polymerase Chain Reaction
NFC	Near Field Communication
OTG	On The Go
GPS	Global Positioning System
MMI	Man Machine Interface
BTB	Battery Terminal Block
SLP	Systematic Layout Planning
LIFO	Last In, First Out
FIFO	First In, First Out
UML	Unified Modeling Language
TQM	Total Quality Management
FMEA	Failure Modes and Effects Analysis
ERP	Enterprise Resource Planning
BOM	Bill of Materials

ABSTRACT

Assembly lines play a crucial role in contemporary mobile phone manufacturing, providing a well-established approach to boost efficiency and productivity. In Pakistan, there has been notable expansion in the local assembly of smart and feature phones, underscoring the need for ongoing enhancements through effective line balancing techniques to maintain competitiveness. Assembly lines remain a cornerstone in mobile phone production, offering a traditional yet highly effective method of manufacturing. In Pakistan specifically, a significant portion of smart and feature phones are now assembled locally, demonstrating a consistent increase in domestically produced units since the beginning. However, to ensure continuous productivity and competitiveness, it is essential to continually refine operations through effective line balancing strategies This paper applies principles of industrial engineering to optimize mobile phone assembly lines. Beginning with a detailed process layout analysis to identify inefficiencies and establish a baseline for improvement, the study focuses on bottleneck identification, defect root causes, and the elimination of non-value-added activities. The objective is to propose strategies aimed at enhancing productivity and efficiency by leveraging techniques such as time motion studies, identification of longest task times, predecessors, and other line balancing methodologies. Through these approaches, improvements in the assembly process are identified, ultimately leading to increased operational effectiveness. The study contributes to the field by showcasing practical applications of industrial engineering principles in optimizing assembly line operations within the mobile phone manufacturing industry, thereby advancing operational efficiency. The research commenced by conducting a process layout analysis to gather fundamental data on line balancing, which served as the foundation for the current assembly line arrangement. Subsequently, an assessment of bottlenecks and the root causes of recurrent defects was carried out to prioritize specific issues for resolution, with a particular focus on deviations from predecessor tasks. Non-value-added activities were then examined to pinpoint areas ripe for enhancement. Subsequent to this, relevant data concerning increased material scrap and instances of reworking preceding task modifications was collected. Finally, the study concluded with the presentation of an optimized and effective balance plan, consolidating the insights and recommendations obtained from the preceding analyses.

Keywords: Lean Manufacturing, Line Balancing, Operational Efficiency, Longest Operating Time Rule, Line Balancing Techniques, Mobile Assembly Plant, Cycle Time, Delay Time, Throughput, Cost Effectiveness, Enhancing Efficiency, Process Enhancement, Optimization.

CHAPTER 1: INTRODUCTION

1.1. Background and Context of Smart Phone Assembling

The mobile phone industry has undergone a transformative journey from its early beginnings to its current status as a vital component of the global economy. This evolution is mirrored in Pakistan, where the mobile phone assembly sector has emerged as a significant player. The sector's growth reflects broader economic trends and highlights the country's potential as a hub for mobile phone manufacturing.

1.1.1. Historical Background and Initial Development

In the early 2000s, Pakistan's involvement in the mobile phone industry was limited to the import of fully assembled devices. The market was dominated by global brands importing their products into the country. However, as technology advanced and the demand for mobile phones grew, Pakistan's role began to shift from merely being a consumer market to becoming a significant player in the assembly and manufacturing domain.

The first signs of local assembly began to appear in the 2010s when international brands started to set up assembly operations in the country. This move was driven by several factors, including government incentives, reduced import duties on mobile components, and the desire to cater to the local market more effectively.

1.1.2. Growth of the Mobile Phone Assembly Sector in Pakistan

Emergence of Local Assembly Plants: The last decade has seen a marked increase in mobile phone assembly operations in Pakistan. Major international brands have established or expanded their local assembly facilities, contributing significantly to the sector's growth.

Tecno Mobile: Tecno, a subsidiary of Transsion Holdings, set up its assembly plant in Pakistan in 2016. The company's focus on affordable smartphones has resonated with Pakistani consumers, leading to increased market penetration and growth.

Infinix: Also part of Transsion Holdings, Infinix established its assembly operations in Pakistan around the same time as Tecno. Infinix's strategy emphasizes high-performance smartphones at competitive prices, which has further boosted its market presence.

Realme: Realme, a subsidiary of Oppo, began local assembly in Pakistan to meet the growing demand for its smartphones. The company's emphasis on innovation and affordability has made it a significant player in the Pakistani market.

Samsung: Samsung's decision to establish an assembly plant in Pakistan reflects its commitment to the region. By assembling devices locally, Samsung aims to enhance its market reach and offer cost-effective solutions to Pakistani consumers.

Itel: Itel, another brand under Transsion Holdings, has also entered the Pakistani assembly sector. Its focus on budget-friendly smartphones has strengthened its position in the local market.

Vigo: Vigo Mobile, known for its cost-effective devices, has set up assembly operations in Pakistan, contributing to the expansion of the local assembly industry.

1.1.3. Economic Impact

The growth of the mobile phone assembly sector in Pakistan has had several positive economic effects:

Job Creation: Local assembly plants have created thousands of jobs, ranging from assembly line workers to managerial positions. This has had a direct impact on employment levels in the region.

Local Component Manufacturing: The rise of assembly operations has spurred the development of local component manufacturing, reducing reliance on imports and supporting the broader electronics industry.

Infrastructure Development: The establishment of assembly plants has led to improvements in infrastructure and logistics, contributing to overall industrial growth.

1.1.4. Market Dynamics and Economic Growth

Market Size and Growth: The mobile phone market in Pakistan has seen significant growth over the years. The increase in local assembly has contributed to this expansion by making smartphones more affordable and accessible. As of recent estimates, Pakistan's mobile phone market continues to grow, driven by rising consumer demand and the proliferation of technology.

Government Support and Policies: The Pakistani government has played a crucial role in supporting the local mobile phone assembly sector. Policies such as tax incentives, reduced import duties on components, and investment subsidies have created a favorable environment for both local and international players.

Investment and Development: Investments in the mobile phone assembly sector have not only increased local manufacturing capabilities but have also attracted foreign investment. Companies are increasingly viewing Pakistan as a viable location for assembly and manufacturing due to its strategic position and growing consumer base.

1.1.5 Growth Opportunities in the Pakistani Mobile Phone Market

Expanding Consumer Base: Pakistan's growing population and increasing smartphone penetration present significant opportunities for further expansion. As more consumers gain access to mobile technology, the demand for affordable and feature-rich smartphones is expected to rise.

Technological Advancements: The rapid evolution of smartphone technology, including advancements in 5G, AI, and other innovations, presents opportunities for local assembly plants to stay competitive. By adopting and integrating these technologies, Pakistani assembly operations can enhance their offerings and meet evolving consumer needs.

Regional Market Potential: Pakistan's strategic location in South Asia provides access to a broader regional market. The country's growing role as an assembly hub can help companies tap into regional demand and strengthen their market presence in neighboring countries.

Increased Local Production: Continued growth in local production capabilities can reduce the reliance on imports and support the development of a robust local electronics industry. This, in turn, can contribute to economic growth and industrial diversification.

E-commerce and Digital Integration: The rise of e-commerce and digital platforms in Pakistan offers new channels for reaching consumers. Local assembly plants can leverage these platforms to expand their market reach and enhance their sales strategies.

1.1.6. Challenges and Considerations

Regulatory Hurdles: Despite the growth opportunities, the industry faces regulatory challenges, including bureaucratic hurdles and inconsistent policies. Addressing these issues is crucial for sustaining growth and attracting further investment.

Economic Fluctuations: Economic fluctuations and inflation can impact consumer spending and manufacturing costs. It is important for companies to develop strategies to mitigate these risks and maintain competitiveness.

Competition and Innovation: The competitive landscape in the mobile phone market requires continuous innovation and differentiation. Local assembly plants must stay ahead of technological trends and market demands to remain relevant.

1.1.7. Importance of Efficiency and Cost-Effectiveness

Efficient manufacturing processes enable companies to be more agile and responsive to changes in the market. This flexibility is important for adapting to new trends, customer preferences, and technological advancements. In a rapidly evolving sector, the ability to quickly adjust production strategies can provide a competitive edge.

Addressing Market Demand in Pakistan: In Pakistan, the demand for mobile phones surpasses local production capabilities. As a result, enhancing efficiency in mobile phone assembly is crucial to bridging this gap. By optimizing assembly processes, manufacturers can increase production volumes to better match demand, reducing the reliance on imports and ensuring that consumers have access to the latest devices.

Competitive Pricing and Market Penetration: The mobile phone market in Pakistan is highly competitive, with numerous brands vying for consumer attention. Cost-effectiveness in assembly operations allows manufacturers to offer competitive pricing, which is particularly important in a price-sensitive market. Lower production costs enable companies to provide more affordable options without compromising on quality, thereby increasing their market share and appealing to a broader audience.

Supporting Local Economic Growth: The expansion of the mobile phone assembly sector in Pakistan has significant implications for the local economy. By improving efficiency and cost-effectiveness, local manufacturers can enhance their output, create jobs, and stimulate related industries. This economic impact extends beyond the assembly plants, contributing to the overall growth of the country's industrial and technological sectors.

Encouraging Investment and Innovation: Efficient and cost-effective assembly processes can attract further investment into the mobile phone sector. Investors are more likely to commit resources to markets where companies demonstrate operational excellence and financial prudence. Additionally, cost savings achieved through efficiency can be reinvested in research and development, fostering innovation and the development of new technologies.

Enhancing Global Competitiveness: For Pakistani mobile phone manufacturers aiming to compete on a global scale, efficiency and cost-effectiveness are vital. To export products internationally, local manufacturers must adhere to global standards while keeping costs manageable. By adopting efficient practices and cost-effective strategies, Pakistani companies can position themselves as competitive players in the global market, expanding their reach beyond domestic borders.

1.1.8. Strategies for Improving Efficiency and Cost-Effectiveness

Implementing Lean Manufacturing Principles: Lean manufacturing focuses on reducing waste and improving process efficiency. Techniques such as just-in-time production, continuous improvement (Kaizen), and value stream mapping can help identify and eliminate inefficiencies, leading to cost savings and increased production capacity.

Investing in Advanced Technologies: Automation and advanced manufacturing technologies can significantly enhance efficiency. Robotics, artificial intelligence, and data analytics can streamline production processes, improve accuracy, and reduce labor costs. Investing in these technologies can help Pakistani manufacturers keep pace with global standards and improve their competitive position.

Optimizing Supply Chain Management: Effective supply chain management is crucial for maintaining efficiency and controlling costs. By optimizing inventory levels, improving supplier relationships, and enhancing logistics operations, manufacturers can reduce delays and minimize costs associated with material handling and transportation.

Fostering Skilled Workforce: A well-trained and skilled workforce is essential for efficient manufacturing. Investing in employee training and development ensures that workers are equipped with the knowledge and skills needed to operate advanced machinery and implement best practices. This can lead to improved productivity and higher-quality outputs.

Emphasizing Quality Control: Quality control processes help identify and address defects early in the production process. By implementing rigorous quality control measures, manufacturers can reduce the incidence of faulty products, which can otherwise lead to costly recalls and damage to brand reputation.

1.2.Problem Statement

The mobile phone assembly industry, especially in emerging markets like Pakistan, is experiencing several challenges related to efficiency and cost-effectiveness. As the sector continues to grow and evolve, addressing these challenges is crucial for enhancing productivity, optimizing resource utilization, and improving overall operational performance. The main challenges include:

1.2.1 Increasing Efficiency in Early-Stage Industry:

Challenge: The mobile assembly industry in Pakistan is still in its formative stages, which presents unique hurdles in achieving high levels of efficiency. Early-stage industries often face difficulties in streamlining processes and achieving operational excellence due to limited experience and underdeveloped systems.

Impact: The lack of established processes and standards can result in inefficiencies in production, higher costs, and slower response times to market demands. Without continuous improvements in efficiency, companies may struggle to compete with more advanced global players.

Solution: To overcome this challenge, companies need to invest in process optimization and adopt best practices from more mature markets. Implementing lean manufacturing principles, conducting regular efficiency audits, and leveraging industry benchmarks can help drive improvements in operational performance.

1.2.2. Enhancing Productivity

Challenge: Productivity is a critical factor for success in the mobile assembly sector. Achieving high productivity levels is essential for meeting market demands and staying competitive. However, many local assembly operations face challenges related to workforce management, production processes, and technology adoption.

Impact: Low productivity can lead to increased production costs and slower time-to-market. It also limits the ability to scale operations and respond to fluctuations in consumer demand effectively.

Solution: Improving productivity requires a multifaceted approach, including investing in automation, optimizing production workflows, and enhancing workforce training. Adopting advanced technologies such as robotics and AI can help streamline operations and boost productivity.

1.2.3. Optimizing Resource Utilization

Challenge: Efficient utilization of resources, including materials, labor, and equipment, is crucial for maintaining cost-effectiveness in mobile assembly. However, resource wastage and suboptimal use of assets can hinder overall efficiency.

Impact: Inefficient resource utilization can result in higher production costs, reduced profit margins, and increased environmental impact. It also affects the ability to maintain competitive pricing and operational sustainability.

Solution: To address this challenge, companies need to implement effective resource management practices. This includes improving inventory management, reducing material waste through better quality control, and ensuring optimal use of machinery and labor.

1.2.4. Improving Line Balancing

Challenge: Line balancing, which involves ensuring that each stage of the production process operates at optimal capacity, is a significant challenge for mobile assembly operations. Many assembly lines have not yet achieved optimal balance, resulting in bottlenecks and inefficiencies.

Impact: Poor line balancing can lead to uneven workloads, production delays, and increased labor costs. It also affects overall throughput and the ability to meet production targets.

Solution: Addressing line balancing issues requires a thorough analysis of the production process to identify and resolve bottlenecks. Techniques such as time and motion studies, process mapping, and workflow optimization can help achieve better balance and improve overall efficiency.

1.3. Thesis Aim

The aim of this thesis is to develop and implement standardized line balancing techniques specifically tailored for mobile assembly operations in Pakistan. The objective is to establish comprehensive and uniform practices to optimize workflow distribution, thereby minimizing bottlenecks and enhancing overall production efficiency. Key goals include reducing operational costs, improving throughput, and increasing responsiveness to market demands. This will be achieved through a systematic analysis of current practices to identify bottlenecks, followed by the development and implementation of best practices in line balancing techniques. The impact on production efficiency and cost-effectiveness will be evaluated to ensure the success of these standardized practices. Enable mobile assembly companies in Pakistan to achieve higher productivity and competitiveness in the global market.

1.4. Objectives of the Study

The primary objective of this study is to optimize assembly line operations in the mobile phone manufacturing industry in Pakistan through the application of industrial engineering principles, with a specific focus on effective line balancing techniques. The objectives can be categorized into several key areas:

1.4.1. Process Optimization and Efficiency Enhancement

The study aims to conduct a detailed process layout analysis to identify inefficiencies within current assembly line configurations. By establishing a baseline for improvement, the research seeks to pinpoint bottlenecks, root causes of defects, and non-value-added activities that hinder productivity. Through this analysis, the objective is to propose and implement strategies aimed at enhancing overall efficiency and operational effectiveness. Techniques such as time motion studies, identification of longest task times, and analysis of predecessor relationships will be utilized to streamline operations and optimize workflow distribution.

1.4.2. Bottleneck Identification and Resolution

A critical aspect of the study involves identifying bottlenecks in the assembly process that contribute to delays and inefficiencies. By conducting thorough assessments and root cause analyses of recurrent defects, particularly focusing on deviations from predecessor tasks, the research aims to prioritize specific issues for resolution. The objective is to implement targeted interventions that alleviate bottlenecks and enhance the flow of production, thereby increasing throughput and reducing cycle times.

1.4.3. Reduction of Non-Value-Added Activities

Non-value-added activities significantly impact operational efficiency by consuming resources without contributing to product quality or customer value. This study will examine existing non-value-added activities within the assembly process, aiming to identify areas ripe for enhancement. By eliminating or minimizing these activities, the objective is to streamline operations, reduce waste, and optimize resource utilization.

1.4.4. Development of an Optimized Balance Plan

Building on the findings from process analysis and bottleneck resolution, the study aims to develop and present an optimized balance plan for mobile phone assembly lines. This plan will consolidate insights and recommendations derived from the preceding analyses, providing a structured framework for enhancing productivity and competitiveness in local manufacturing operations.

1.4.5. Future Research Directions

The study also outlines future research directions aimed at advancing assembly line optimization in the mobile phone manufacturing sector. Key areas of interest include the integration of artificial intelligence for adaptive decision-making, advancements in predictive maintenance strategies, and exploration of hybrid optimization techniques. These initiatives aim to further enhance efficiency, maintain competitive advantage, and support sustainable growth in the global mobile phone market.

1.5. Scope and Limitations

1.5.1. Scope

This study focuses on optimizing assembly line operations within the mobile phone manufacturing industry in Pakistan by applying industrial engineering principles, particularly effective line balancing techniques. The scope encompasses several key aspects:

Process Optimization: Conducting a detailed process layout analysis to identify inefficiencies and establish a baseline for improvement in assembly line configurations.

Efficiency Enhancement: Implementing strategies to enhance productivity and efficiency, including time motion studies, identification of longest task times, and analysis of predecessor relationships.

Bottleneck Identification and Resolution: Prioritizing resolution of bottlenecks and root causes of defects through thorough assessments and root cause analyses, with a focus on deviations from predecessor tasks.

Reduction of Non-Value-Added Activities: Identifying and minimizing non-value-added activities to streamline operations, reduce waste, and optimize resource utilization.

Development of an Optimized Balance Plan: Formulating a comprehensive balance plan based on insights and recommendations derived from process analysis and bottleneck resolution.

Future Research Directions: Outlining future research directions such as integrating artificial intelligence for decision-making, advancing predictive maintenance strategies, and exploring hybrid optimization techniques.

The scope of this study is to contribute practical insights into improving assembly line efficiency in the context of local mobile phone manufacturing, aiming to enhance competitiveness and operational effectiveness.

1.5.2. Limitations

Despite the comprehensive scope, this study has certain limitations:

Industry Specificity: Findings and recommendations are primarily tailored to the mobile phone manufacturing industry in Pakistan and may not directly apply to other manufacturing sectors or global contexts without adaptation.

Data Availability: The effectiveness of recommendations may be influenced by the availability and accuracy of data provided by industry partners and stakeholders.

Resource Constraints: The implementation of advanced technologies and strategies, such as artificial intelligence and predictive maintenance, may be limited by resource constraints and technological readiness in the local industry.

Generalizability: While the study aims to provide insights applicable to the broader mobile phone manufacturing sector, the specific conditions and practices within individual assembly plants may vary, affecting generalizability.

Temporal Factors: The study's findings and recommendations reflect conditions and practices at a specific point in time and may require periodic updates to address evolving industry standards and technological advancements. Regulatory and Environmental Factors: Compliance with regulatory requirements and environmental standards may pose constraints on the implementation of certain optimization strategies.

In conclusion, while this study endeavors to offer valuable insights and recommendations for optimizing assembly line operations in the mobile phone manufacturing industry in Pakistan, these must be considered within the context of the identified limitations to ensure practical applicability and relevance.

1.6. Definitions and Terminology

1.6.1. Line Balancing Overview

Line Balancing involves assigning tasks to workstations in such a way that each workstation has an approximately equal amount of work, thereby minimizing the total production time and avoiding bottlenecks. The primary objective is to ensure a smooth flow of work and efficient use of resources, which is especially crucial in high-volume production settings like smartphone assembly lines.

1.6.2. Key Objectives of Line Balancing:

Minimize Idle Time: Ensure that workstations are occupied as efficiently as possible to reduce the downtime of workers and machines.

Maximize Efficiency: Achieve a balanced distribution of work to improve throughput and reduce production time.

Reduce Bottlenecks: Avoid overloading any single workstation to prevent delays and production slowdowns.

1.6.3. Line Balancing Rules

Several rules and methods exist for achieving line balance, each with distinct advantages and suitability depending on the production context. The most common line balancing rules include:

Longest Operating Time (LOT)

Description: Assign the task with the longest time requirement to the first workstation, then proceed to the next longest task for subsequent workstations.

Strengths: Effective in minimizing the risk of bottlenecks by addressing the most time-consuming tasks first. This approach is particularly useful when tasks vary significantly in duration.

Weaknesses: May not always result in the most balanced line if the longest tasks are not evenly distributed among workstations.

Shortest Operating Time (SOT)

Description: Start by assigning the shortest tasks to the available workstations.

Strengths: Can quickly fill workstations with smaller tasks, potentially reducing the overall cycle time.

Weaknesses: May lead to imbalanced workloads, with some workstations having a heavy load while others remain underutilized.

Most Predecessors Rule (MPR)

Description: Assign tasks with the most immediate predecessors (i.e., tasks that require completion of several prior tasks) first.

Strengths: Helps in managing task dependencies efficiently and ensures that tasks are completed in the correct order.

Weaknesses: May not always result in an evenly distributed workload across workstations.

Least Predecessors Rule (LPR)

Description: Assign tasks with the fewest predecessors first.

Strengths: Can facilitate a smooth start to the assembly process by tackling tasks that are less dependent on previous operations.

Weaknesses: Might lead to delays later in the process if critical tasks are not prioritized.

Ranked Positional Weight Rule (RPWR)

Description: Rank tasks based on their positional weight, which is the sum of the task times and the times of all dependent tasks.

Strengths: Provides a comprehensive approach to balance by considering both task duration and dependencies.

Weaknesses: Complexity in computation and implementation.

1.6.4. Suitability of the Longest Time Rule for Smartphone Assembly Lines

Minimizes Bottlenecks

By prioritizing tasks with the longest time requirements, the LTR helps in addressing potential bottlenecks early in the process. In smartphone assembly, where certain components or tasks are more complex and time-consuming, this rule ensures that these critical steps are handled promptly.

Balances Workload

Helps in distributing work more evenly by ensuring that tasks with significant time requirements are assigned first. This is crucial in assembly lines where the complexity of tasks can vary widely.

Improves Efficiency

By focusing on the longest tasks, the LTR reduces the likelihood of having workstations with excessive idle time. This is particularly beneficial in smartphone assembly, where synchronization between different stages of production is key to maintaining overall efficiency.

1.6.5. Implementing Lean Manufacturing Principles in Mobile Phone Assembly Plants

Introduction

Lean manufacturing, a production practice aimed at minimizing waste and maximizing value, is particularly relevant in high-tech and high-volume industries such as mobile phone assembly. This chapter explores the theory and practical application of lean manufacturing principles within the context of a mobile phone assembly plant. We will discuss the core principles of lean manufacturing, their relevance to mobile phone assembly, and strategies for effective implementation.

Lean Manufacturing: An Overview

Lean manufacturing, rooted in the Toyota Production System (TPS), focuses on enhancing operational efficiency by eliminating waste, improving quality, and optimizing production processes. The central tenets of lean manufacturing revolve around creating value for the customer while minimizing non-value-adding activities.

Core Principles of Lean Manufacturing:

Value Definition: Understanding what constitutes value from the customer's perspective is fundamental. This involves identifying the features and characteristics of a product that customers are willing to pay for.

Value Stream Mapping: Mapping out all the steps involved in the production process to identify and analyze value-adding and non-value-adding activities. The goal is to streamline processes and remove waste.

Creating Flow: Ensuring a smooth and uninterrupted flow of materials and information throughout the production process. This includes balancing workloads and minimizing delays.

Establishing Pull: Implementing a pull-based system where production is driven by actual customer demand rather than forecasts. This helps in reducing overproduction and excess inventory.

Pursuing Perfection: Continuously improving processes and eliminating waste through incremental changes. This principle emphasizes a culture of ongoing improvement and problem-solving.

1.6.6. Lean Manufacturing Principles in Mobile Phone Assembly Plants

1. Develop a Lean Strategy

2. Train and Empower Employees

3. Implement Lean Tools and Techniques

4. Monitor and Review Performance

5. Foster a Culture of Continuous Improvement

1.7. Summary

This chapter establishes the context and framework for the thesis on optimizing mobile phone assembly lines in Pakistan. It begins with an overview of the mobile phone industry, emphasizing its importance and current trends that impact efficiency and cost-effectiveness.

The problem statement identifies key challenges in the industry, including inefficiencies in early-stage operations, low productivity, suboptimal resource utilization, and line balancing issues. It highlights the critical gaps that the thesis aims to address, specifically the need for standardized line balancing techniques to resolve bottlenecks and enhance overall production efficiency.

The study's objectives are clearly outlined, focusing on process optimization, bottleneck resolution, reduction of non-value-added activities, development of an optimized balance plan, and identifying future research directions. These objectives are designed to improve operational effectiveness and competitiveness within the mobile phone assembly sector.

The scope of the study is defined, detailing the specific areas of focus, including process layout analysis, line balancing strategies, and lean manufacturing principles. The limitations of the study are also acknowledged, such as industry specificity, data availability, and resource constraints.

The structure of the thesis is presented, providing an overview of each chapter, from the literature review to practical implementation and recommendations. Definitions and terminology related to line balancing and lean manufacturing are explained to ensure clarity and understanding.

In summary, the chapter sets the stage for a comprehensive exploration of assembly line optimization, framing the study's context, objectives, and scope while outlining the methodology and expected outcomes.

CHAPTER 2: LITERARTURE REVIEW

According to Nils Boysen [1] the Simple Assembly Line Balancing Problem (SALBP) is a fundamental optimization challenge in operations research, akin to the Traveling Salesman Problem in transportation. It involves assigning tasks to a series of workstations in an assembly line, aiming to minimize the number of stations required while ensuring each station’s workload adheres to a fixed cycle time. Since its formalization by Salveson in 1955, SALBP has seen extensive research and the development of various exact and heuristic methods. The problem's practical relevance spans industries like automotive manufacturing, where complex, large-scale lines pose significant planning challenges. While SALBP-1 focuses on minimizing station count for a set cycle time, SALBP-2 targets reducing cycle time for a fixed number of stations. The field has evolved with the introduction of the General Assembly Line Balancing Problem (GALBP), which addresses more complex scenarios such as U-shaped lines and stochastic task times. Despite advances, real-world applications often lag behind theoretical solutions, highlighting ongoing research needs and the importance of adapting optimization techniques to modern industry challenges. As per Uğur Özcan & Bilal Toklu [2] assembly lines are crucial for producing high-volume standardized products, involving a sequence of stations where tasks are performed according to precedence constraints and a set cycle time. The Assembly Line Balancing (ALB) problem focuses on optimizing task assignments to stations to achieve specific objectives, such as minimizing the number of stations for a given cycle time or minimizing the cycle time for a fixed number of stations. Key constraints in ALB include ensuring each task is assigned to one station, respecting precedence relationships, and keeping task times within the cycle time. Assembly lines are typically categorized into straight and U-shaped lines, and further classified by the number of product models produced. Two-sided assembly lines, where both sides of the line are used, offer advantages like reduced line length and costs compared to one-sided lines. Real-world constraints in two-sided lines include zoning, positional, and synchronism constraints. Despite extensive research into ALB, two-sided assembly line balancing (TALB) remains less explored. Recent studies have applied various methods, including genetic algorithms, ant colony optimization, and tabu search, to address TALB challenges. The paper at hand introduces a tabu search algorithm to maximize line efficiency and minimize smoothness in TALB, with a detailed performance evaluation provided.

Adil Baykasoğlu [3] said that an assembly lines involve assigning a finite number of tasks to workstations to meet technological and organizational constraints while completing the assembly process in sequence. These problems are classified based on factors like the variety of models produced, task time variability, and line layout. The Simple Assembly Line Balancing Problem (SALBP) is a prominent example, where tasks with deterministic times must be arranged in a sequence, adhering to precedence constraints. SALBP is divided into two types: Type I aims to minimize the number of workstations for a fixed cycle time, while Type II seeks to minimize cycle time with a fixed number of workstations. This paper focuses on Type I SALBP with a straight line layout, aiming to minimize workstations and balance workloads. SALBP is NP-hard, and various methods such as exact algorithms, heuristics, and metaheuristics have been explored to find solutions. Priority rule-based methods, such as the ranked positional weight, are often used due to their efficiency in practice. This study introduces a novel approach using Genetic

Programming (GP) to develop composite task assignment rules, combining various attributes of tasks to enhance assembly line balance. The proposed GP-based method aims to improve the efficiency of task assignment rules and is tested through extensive computational analysis. According to adi Gokcen [4] traditional assembly line balancing involves distributing tasks across workstations to achieve equal workloads while adhering to precedence constraints. Since the problem's inception in 1950, various techniques have been developed to address it. Recently, U-type layouts have become popular due to their efficiency and flexibility, often requiring fewer workstations than straight lines by considering both predecessor and successor tasks. The U-type Assembly Line Balancing (SULB) problem extends traditional balancing methods, introducing additional complexity and computational challenges. Notably, shortest route formulations have been used to simplify solving these problems by focusing on efficient task assignments. The current study builds on this approach to develop a model for SULB, aiming to minimize the number of workstations while meeting all constraints, based on known task times and precedence relations.

As per Sener Akpınar [5] the shift towards consumer-centric markets has driven a transition from low-mix/high-volume to high-mix/low-volume manufacturing strategies. Traditional single-model assembly lines, suited for low-variability scenarios, are increasingly inadequate for this new demand, leading manufacturers to adopt mixed-model assembly lines. These lines can handle multiple product models on a single line, optimizing resource use and reducing costs. The mixed-model assembly line balancing problem (MMALBP) involves two main types: design (Type-I) and redesign (Type-II). Type-I addresses new line setups with predictable demand, while Type-II focuses on adjusting existing lines due to changes in products or processes. Both types aim to efficiently assign tasks while respecting precedence constraints and minimizing either the number of workstations or cycle time. To tackle these complex and NP-hard problems, recent approaches integrate hybrid algorithms combining ant colony optimization (ACO) with genetic algorithms (GA), addressing challenges like sequence-dependent setup times and zoning constraints. These hybrids leverage the strengths of different optimization techniques to enhance performance in real-world scenarios. Whereas Bilal Toklu [6] said that the Assembly Line Balancing Problem (ALBP) involves optimizing task assignments across workstations to meet a specific cycle time while adhering to constraints such as precedence and assignment rules. In one-sided assembly lines, tasks are allocated to a linear sequence of stations, whereas two-sided lines use both sides of the line simultaneously, allowing parallel task execution and potentially reducing line length and costs. The problem is NP-hard, with two-sided assembly line balancing (TALBP) classified into minimizing the number of mated-stations (TALBP-I) or minimizing cycle time for a fixed number of mated-stations (TALBP-II). Solutions range from exact methods like mixed integer programming to heuristic approaches such as genetic algorithms and ant colony optimization. Recent studies have explored various techniques, including fuzzy goal programming for handling imprecise objectives, to address the complexity and practical challenges in optimizing assembly lines.

Ugur Özcan [7] in his other research also explained that two-sided assembly lines, used for producing large products like automobiles and buses, utilize both sides of the line in parallel, allowing for potentially shorter lines and reduced costs. However, while previous studies on two-sided assembly lines assume deterministic task times, real-world applications often involve variability due to factors such as machine breakdowns or worker differences. This paper addresses the balancing of two-sided assembly lines with stochastic task times (STALBP) by proposing a chance-constrained, piecewise-linear mixed integer program (CPMIP) and a simulated annealing (SA) algorithm to solve it. The effectiveness of these approaches is evaluated through test problems, demonstrating their utility in managing task time uncertainty. The paper builds on the foundation of assembly line balancing studies and aims to fill the gap in addressing stochastic elements in two-sided assembly lines, a topic previously unexplored in the literature.

Alexandre Dolgui [8] said that line balancing is a complex combinatorial optimization problem that has been extensively studied and is recognized as NP-hard, involving the challenge of efficiently allocating tasks to workstations within various manufacturing contexts such as assembly, machining, and disassembly. This paper aims to review recent advancements in balancing flow lines by analyzing approximately 300 studies published from 2007 to 2012, highlighting the evolution of models, constraints, and objective functions used in different industrial environments. Initially, the introduction outlines the significance of line balancing in the design and operation of flow lines, noting the interplay between product design, process selection, and line configuration. The survey categorizes the core elements of line balancing problems, including the number of lines to be balanced, task attributes, workstation attributes, constraints, and criteria for evaluating solutions. It differentiates between single-model lines, which focus on one product type with consistent task subsets across cycles, and mixed-model lines, which handle multiple product variations simultaneously. The paper reviews methodologies for solving these problems, from exact algorithms to approximate methods, including heuristics, metaheuristics, and multi-criteria decision-making approaches. Furthermore, it discusses the practical implications of balancing lines in different settings, such as automated machining versus manual disassembly, and presents a new taxonomy to address both traditional and emerging issues in line balancing research. By synthesizing recent literature and providing a comprehensive analysis, the survey aims to offer valuable insights and identify gaps in current research, guiding future studies and practical applications in the field of line balancing.

Erdal Erel [9] further elaborated that the assembly line balancing problem has garnered significant attention from production and operations management scholars over the past four decades. Despite numerous studies exploring various facets of this problem, research specifically focusing on mixed-model assembly lines remain ns relatively sparse. In this paper, we introduce a binary integer programming model tailored for the mixed-model assembly line balancing problem and discuss its computational characteristics. The problem is known to be NP-hard, particularly because even a single-model scenario with no precedence constraints reduces to the bin packing problem, which is NP-hard in the strong sense. Thus, the combinatorial complexity of mixed-model line balancing complicates the quest for optimal solutions, especially since mixed-model lines are prevalent in industry due to the demand for producing multiple models to enhance customer satisfaction. The mixed-model assembly line balancing problem involves assigning a set of tasks to a sequence of workstations for multiple product models, given the performance times of tasks and precedence constraints, to optimize certain performance metrics. Salveson was among the first to propose a mathematical model for single-model assembly line balancing in the 1960s and 70s, leading to various heuristic solutions and some optimal-seeking algorithms such as integer programming models, shortest-route network formulations, and dynamic programming approaches. Despite these advances, the number of studies addressing mixed-model lines remains limited, with Roberts and Villa among the few who have explored binary integer programming models, though their models were hampered by the rapid growth in variables and constraints. Recent efforts like Berger et al.'s branch-and-bound algorithm have tackled specific cases of mixed-model problems. Our paper proposes an improved integer programming model that leverages properties to mitigate the rapid increase in variables, although its NP-hard nature means it is still challenging to apply to large, realistic problems. The model also serves as a benchmark for evaluating heuristic methods designed for mixed-model assembly lines. The structure of this paper includes a detailed presentation of the binary integer programming model, an illustrative example to clarify the model, a discussion of its computational properties, and concluding remarks. The model incorporates assumptions such as known task performance times, fixed precedence relations, and consistent station numbers across models. By combining precedence diagrams of different models, the model significantly reduces the number of variables and constraints, providing a more manageable approach to solving the mixed-model assembly line balancing problem.

Ugur Ozcan [10] in his paper said that two-sided assembly lines are crucial for producing large-scale products like automobiles and buses, utilizing both sides of the line to enhance efficiency. Although research has largely focused on one-sided assembly lines, two-sided assembly line balancing (TALBP) has been less explored. This paper introduces the parallel two-sided assembly line balancing problem (PTALBP), which involves optimizing the balance of multiple two-sided assembly lines running in parallel. We propose a tabu search algorithm to address PTALBP, aiming to minimize the number of stations needed and reduce idle times. The paper details the algorithm's design, provides illustrative examples, and discusses its performance and implications for future research. In a paper Yuri N. Sotskov [11] said that assembly lines are crucial for large-scale production, optimizing task distribution to enhance efficiency. This review examines recent advancements in assembly line design, balancing, and scheduling, particularly addressing uncertainties like stochastic, fuzzy, and uncertain parameters. It covers both deterministic models and more complex formulations that account for real-world variations, including new algorithms and methods for disassembly lines. By surveying developments over recent decades, the paper highlights key challenges and proposes future research directions to improve assembly line performance and adaptability. Matthias Amen [12] paper explores cost-oriented assembly line balancing, focusing on minimizing the cost per product unit rather than just the number of stations or cycle time. It introduces a refined objective function and formal problem statement, and discusses enhancements to existing models, including the shift from the "maximally-loaded-station-rule" to the more complex "two-stations-rule." The study provides new and improved bounds for station numbers and costs, integrates these into general and specialized optimization methods, and offers an overview of advanced techniques and challenges in the field, drawing on Amen's previous research for further insights. Andrea Ascheri [13] explained assembly lines as a complex, knowledge-intensive process that heavily relies on the experience of engineers, historical lessons, and intricate sets of rules. This process often involves high costs, lengthy lead times, and significant risks of rework. To address these challenges, the paper proposes a methodology utilizing Knowledge-Based Engineering (KBE) and knowledge representation techniques. This approach aims to streamline the assembly line configuration process by integrating best practices and system engineering rules into a user-friendly platform. The methodology allows for the efficient design of initial line layouts based on predefined requirements, such as cycle time. The paper also extends the KBE approach to a specific case study in the powertrain sector, demonstrating how collected knowledge can be applied to real-world scenarios. By automating and formalizing the design process, this approach seeks to mitigate risks and reduce costs associated with assembly line design.

Bai Ying [14] explained his thoughts as In response to the mixed-model assembly line (MMAL) balancing problem, his paper introduces a mathematical model that integrates two crucial factors: the number of workstations and assembly line efficiency. To solve this complex problem, a new hybrid genetic algorithm is developed, combining genetic algorithms (GA) with simulated annealing (SA) to avoid premature convergence and improve global optimization. The simulation results demonstrate that this hybrid approach outperforms traditional methods in efficiency and optimization performance. The proposed model addresses the challenges of balancing MMALs by minimizing idle time and maximizing efficiency, and the hybrid algorithm effectively finds optimal solutions, as evidenced by comparative results with existing algorithms. Adil Baykasoglu [15] paper addresses the assembly line balancing problem (ALBP) by introducing a novel multiple-objective simulated annealing (SA) algorithm for optimizing both simple (line) and U-type assembly lines. The proposed algorithm aims to maximize the "smoothness index," which measures the even distribution of tasks across workstations, and minimize the number of workstations required. By integrating task assignment rules within a simulated annealing framework, the algorithm effectively navigates the complex search space of possible solutions. Testing on various literature problems demonstrated that the algorithm achieves optimal solutions quickly, outperforming existing methods in terms of computational efficiency and solution quality. This approach offers a practical and robust method for improving production line efficiency by balancing tasks while adhering to precedence constraints and cycle time limits.

Ilana Berger [16] paper tackles the challenge of balancing a flexible manufacturing system where multiple products each require a series of sequential, non-preemptive tasks, with some tasks potentially being shared among products. The goal is to minimize the number of workstations needed while ensuring that tasks are performed in the correct sequence and within a specified time frame per workstation. To address this, the paper introduces a branch-and-bound algorithm featuring significant improvements over existing methods: an enhanced lower-bounding procedure and a more effective partitioning scheme. The algorithm can function as either a heuristic or an exact solution method, depending on its implementation. Empirical tests on randomly generated problems demonstrate that the proposed improvements lead to effective solutions, showcasing the algorithm's capability in both minimizing the number of workstations and handling the complexity of task sequencing and time constraints.Nils Boysen [17] said that assembly line balancing involves assigning tasks to workstations to optimize objectives such as minimizing the number of workstations or cycle time, while adhering to precedence constraints. Since Salveson's 1955 formulation of the Simple Assembly Line Balancing Problem (SALBP), significant research has focused on various SALBP sub-problems and their solutions through exact and heuristic methods. The General Assembly Line Balancing Problem (GALBP) expands this scope to include complex real-world scenarios like parallel workstations and stochastic processing times. To address these complexities, the Avalanche algorithm was introduced, offering a two-stage approach: first, generating feasible task sequences using heuristic search, and second, optimizing task assignments through a shortest-path problem in an assignment graph. This approach provides a versatile and efficient solution to both SALBP and GALBP, demonstrating its effectiveness in handling diverse assembly line configurations.

Buchari [18] said that efficient production processes are crucial for optimizing operational performance in manufacturing environments. At PT. XYZ, a wood processing company specializing in semi-finished wood products on a make-to-order basis, significant inefficiencies have been identified due to an imbalanced production line and irregular material flow patterns. The production line imbalance arises from varying cycle times at different workstations, leading to capacity bottlenecks and material buildup. Furthermore, the irregular layout of the production area contributes to increased material handling distances and workflow disruptions. This study seeks to address these issues by employing the Ranked Positional Weight (RPW) method for line balancing and the Systematic Layout Planning (SLP) method for optimizing the production layout, aiming to enhance overall efficiency and reduce unnecessary material handling distances. Gerald R.Aase [19] explained the transition from straight-line to U-shaped assembly lines represents a significant layout design change aimed at enhancing labor productivity. Advocates of lean manufacturing argue that U-shaped layouts provide several advantages over traditional straight-line systems, particularly in terms of productivity. Despite these claims, empirical data supporting this assertion is limited. This research aims to verify whether U-shaped assembly lines indeed improve labor productivity and under what conditions. Results indicate that while labor productivity can significantly improve with a U-shaped layout in certain scenarios, this is not universally applicable. Factors such as the number of tasks and cycle times play a crucial role in determining the effectiveness of the layout change. The study provides insights into when and how U-shaped layouts can be most beneficial for manufacturing operations.

RICHARD F. DECKRO [20] said that the assembly line balancing problem (ALBP) has evolved significantly since its initial mathematical programming formulations by Salvenson and Bowman in the 1950s and 1960s. Early models focused on single-objective optimization, but recent research has increasingly recognized the need for multi-criteria approaches to address various operational goals simultaneously. Despite extensive literature, including comprehensive reviews by Ghosh and Gagnon, the application of goal programming and multi-objective models remains limited. Notable advancements include Patterson and Albracht's zero-one goal programming model and Rangachari's multiple objective approach, which accommodate complex criteria such as precedence, zoning, and cycle time constraints. Future research is likely to emphasize further development of multi-criteria models and practical implementations to better handle the diverse and often conflicting objectives inherent in assembly line balancing.

Rongli Zhao [21] said that the mobile phone industry is, a dynamic sector within the 3C (Computer, Communication, and Consumer) electronics market, demands optimized production workshop designs due to its rapid product turnover, diverse specifications, and high flexibility requirements. This paper focuses on a specific mobile phone assembly process, employing heuristic balancing methods to integrate production procedures, considering automation levels and production line rhythms. By evaluating the advantages and disadvantages of plug-and-play and unit production line architectures, a hybrid workshop combining these approaches is designed. An optimization model is established to address construction costs and unit area capacity. The design is validated through digital twin semi-physical simulation technology, which aids in achieving production line balance, enhancing efficiency, and reducing costs. This study offers a technical framework for optimizing large-scale mobile phone assembly workshops amid frequent production changes. It provides insights into hybrid production line design and optimization, using digital twins for effective simulation and evaluation. The paper concludes with a review of related studies on facility layout design and production line optimization, highlighting methods and challenges in this evolving field. Rosario Domingo [22] paper examines the internal materials flow in a lean manufacturing assembly line at a Bosch factory in Spain. The objective is to design a handling system for a constrained workspace to address issues with accumulated intermediate stocks of parts. The proposed solution is the implementation of a milkrun handling system, with progress evaluated through lean metrics such as dock-to-dock time and lean rate. The findings indicate that the milkrun system enhances lean metrics by reducing stock levels, work-in-process, and dock-to-dock time, without altering the existing layout and production planning. Although the case study is specific to this plant, the methodology and findings offer valuable insights for similar contexts.

R.O. Edokpia [23] believed that assembly line balancing (ALB) aims to optimize the allocation of tasks across workstations to enhance production efficiency, either by minimizing the number of stations or cycle time, with approaches varying based on task time determinism. Deterministic models, such as the Longest Operation Time (LOT) and Ranked Positional Weight Technique (RPWT), prioritize tasks based on known durations and precedence constraints to ensure an even distribution of work. Stochastic models, addressing variability in task times, employ techniques like probabilistic line balancing to manage uncertainties. Previous research has demonstrated improvements in productivity and efficiency through various heuristic and soft computing methods, yet studies focusing on Nigerian industries are scarce. This study aims to bridge this gap by comparing LOT and RPWT in the context of motorcycle assembly in Nigeria, seeking to propose a more efficient assembly design. Parviz Fattahi [24] said that the mixed-model assembly line (MMAL) involves integrating various models of the same product on a single production line, which addresses the diversification of customer demands. Efficient MMAL operation requires solving two key problems: line design and balancing, and sequencing of different product models. Sequencing is crucial for maintaining consistent production rates and minimizing idle times, which supports the implementation of just-in-time systems. Previous research has explored various methodologies for sequencing, such as nonlinear integer programming and dynamic programming, often addressing objectives like minimizing line length and setup costs while maintaining part usage rates. However, the complexity increases with variable launching intervals between products, which can enhance flexibility but also introduces significant computational challenges. This paper proposes a hybrid metaheuristic algorithm combining simulated annealing and heuristic methods to tackle the sequencing problem with variable intervals, aiming to optimize both idle and utility costs on MMAL systems.

Davide Giglio [25] presented the Multi-Manned Assembly Line Balancing Problem (MALBP) extends the traditional assembly line balancing to scenarios where multiple operators can be assigned to a single workstation, particularly relevant for high-volume, large-size product industries like automotive manufacturing. Unlike simpler models that assume single-manned workstations and fixed production parameters, MALBP accommodates the simultaneous task execution by multiple workers and the variability in worker skills. Recent advancements, such as the mixed-integer programming model proposed by Giglio et al. (2017), aim to minimize operating costs by optimizing both the number of workstations and the distribution of tasks among workers, demonstrating significant improvements over previous models by leveraging worker collaboration and specialized skills. Jun Jin [26] said that technological capability (TC) is pivotal for competitive advantage at various levels, from firms to nations, and has garnered significant attention from both academics and policymakers, especially in developing economies (Lall, 1990; Miyazaki, 1995). While traditional research has focused on heavy and chemical technology industries, there is a notable gap in the study of information and communication technologies (ICT), despite their importance in technological leapfrogging for developing countries (Perez, 1988; Lee and Lim, 2001). Existing models, like Kim's (1980), which outline a linear progression from mature to emerging technologies, do not fully capture the rapid and dynamic TC development observed in fast-growing economies such as China. Recent empirical studies, including those by Gao (2003), suggest that Chinese firms have deviated from this linear model, progressing directly from assimilating mature technologies to innovating their own. This paper seeks to revise Kim's model by examining the TC development of Chinese mobile phone manufacturers through detailed case studies, aiming to propose a refined model that better fits the observed practices in fast-emerging economies.

Yeo Keun Kim [27] paper addresses Two-Sided Assembly Line Balancing (Two-ALB), where tasks must be optimally assigned to both sides of an assembly line, considering directional preferences and precedence constraints. Unlike one-sided assembly lines, Two-ALB involves tasks that may be performed preferentially on the left (L-type) or right (R-type) side, or on either side (E-type). The paper introduces a mathematical formulation to minimize the cycle time while adhering to task assignment constraints and precedence relationships. It also proposes a genetic algorithm (GA) tailored to this problem, enhancing search efficiency and solution quality compared to previous methods. This formulation and GA approach offer significant improvements in balancing production lines for large products like trucks and buses. Whereas Robert Klein [28] said that the Type 2 Simple Assembly Line Balancing Problem (SALBP-2) addresses the challenge of efficiently assigning tasks to workstations on a production line for a single product, given fixed task times and precedence constraints. In SALBP-2, a set of n tasks, each with a specific operation time, must be scheduled across workstations to ensure that all tasks are completed in adherence to their precedence relationships, which dictate that certain tasks must be finished before others can begin. The production rate is determined by a constant pace p, setting the cycle time c, which is the interval between consecutive product units arriving at the workstations. The primary objective of SALBP-2 is to minimize this cycle time by effectively partitioning the tasks into disjoint subsets, or station loads, ensuring that no workstation's workload exceeds the cycle time. To solve SALBP-2, one must determine both a feasible partitioning of tasks that respects precedence constraints and an optimal cycle time. The paper delves into various strategies for determining lower and upper bounds on the cycle time, explores existing solution techniques—particularly those adapted from related problems like SALBP-1—and introduces a novel branch-and-bound algorithm, SALOME-2, which is further enhanced by a bidirectional approach. Through computational experiments, the paper compares these methodologies, aiming to refine production efficiency in scenarios where task times and process configurations may be subject to frequent changes.

JOHN F, KOTTAS [29] paper presented heuristic approach to balancing a single-product paced assembly line with a constant output rate and stochastic task times is designed to minimize both expected labor and incompletion costs, leveraging a computationally simple procedure that is effective for large-scale line balancing problems. This method introduces a new level of realism for paced assembly lines, where task times are variable, by grouping tasks into workstations in a way that optimizes operational efficiency at the given output rate. The primary aim is to balance the tasks across stations to minimize labor costs, which are directly proportional to the number of stations used, and incompletion costs, which arise from tasks not being completed within the allotted cycle time. The trade-off between these costs is critical: while fewer workers (stations) reduce labor costs, increasing the number of tasks per worker raises the likelihood of incomplete tasks, thus increasing incompletion costs. This balancing act is influenced by the stochastic nature of task times, where variations are assumed to be normally distributed and independent. The heuristic involves a step-by-step process, beginning with establishing new stations and assigning tasks based on their expected labor savings versus incompletion costs, with the goal of minimizing the total cost per unit. It accounts for task precedence and varying worker performance, and it can be adjusted for additional constraints like fixed locations and different wage rates. The approach aims to optimize the cycle time while ensuring that tasks are completed within a practical range of the given time constraints, effectively managing the stochastic nature of task performance and achieving a cost-effective line operation.

Joonkoo Lee [30]   text explores the evolution of global production networks (GPNs) and their impact on industrial development, particularly in East Asia, focusing on the mobile phone manufacturing sector. It contrasts earlier concepts such as the “new international division of labor” with the more contemporary GPN framework, highlighting how globalization has led to the fragmentation of production processes across different countries, each specializing in specific value chain activities. This shift has significant implications for economic development, as nations engage in various segments of the global value chain (GVC) and move towards higher-value activities. The study examines the divergent paths of China, Japan, Korea, and Taiwan within the mobile phone industry, revealing that while Japan, Korea, and Taiwan have each found success in different market niches, China's development trajectory is more complex and diversified. This divergence underscores the impact of globalization on development outcomes, as countries navigate varying levels of success and specialization within the GVC. The theoretical debate has shifted from whether economic globalization would lead to convergence towards a common development model to understanding how fragmented and decentralized production influences development paths and outcomes. The study uses a GVC approach to analyze these dynamics, emphasizing the changing nature of global production and its implications for future industrial development in East Asia.

Emanuel Falkenauer [31] said, While traditional Assembly Line Balancing (ALB) models, like the Simple Assembly Line Balancing Problem (SALBP) and its Generalized versions, offer a theoretical foundation, they often fall short in addressing the complexities of real-world applications, particularly in industries such as automotive manufacturing. These models typically assume new assembly lines from scratch and do not account for the intricate realities of rebalancing existing lines, where workstations have unique constraints and specific operational requirements. Real-world scenarios demand solutions that can handle dynamic rebalancing, accommodate fixed and zoned operations, and respect the physical and functional constraints of existing workstations. The gap between academic models and practical needs underscores the necessity for advanced software solutions that integrate these complexities to optimize line efficiency in industrial settings. According to C.N. Vijeyamurthy [32], economic globalization has fundamentally altered industrial development by liberalizing cross-national trade and investment flows, reducing barriers, and establishing new neo-liberal norms and regulations. This transformation is exemplified by the rise of global value chains (GVCs), which fragment production into distinct, value-adding tasks distributed across national borders through offshore outsourcing. A GVC encompasses all activities needed to bring a product from inception to end use, reflecting a shift from traditional centralized production models to a dispersed, interconnected global system. The concepts of global production networks and the new international division of labor underscore this shift, emphasizing the strategic importance of how countries integrate into these value chains. Emerging economies, such as China, India, Brazil, and South

Africa, have become key players in global production networks, altering competitive dynamics and presenting new opportunities for industrial development.

Pinar Tapkan [33]said that the Total Covering Problem (TCP) involves locating the minimum number of facilities (dealers) necessary to ensure that every customer (residential region) is within a specified distance of at least one facility. This problem, critical in areas such as emergency services and public utilities, is formulated as a 0-1 integer programming problem where the objective is to minimize the number of facilities required. In contrast, the Partial Covering Problem (PCP) addresses situations with a fixed maximum number of facilities and seeks to cover as many customers as possible within that limit. The Set Covering Problem (SCP), closely related, focuses on selecting the minimum number of subsets to cover all elements of a set, with TCP being a special case of SCP where the costs are unitary. Additionally, the Anti-Covering Location Problem (ACLP) involves placing facilities so that no two is within a specified distance from each other. These problems can be classified based on the type of coefficients used, such as binary (0-1) in public-service contexts or non-binary in logistics and warehousing. H.S. Wang [34] believes in the production industry, selecting the optimal product plan is crucial due to its impact on overall cost and efficiency, as over 70% of production costs are determined during the design phase, despite design costs being only 6% of total costs. Effective early-stage cost control can prevent issues such as discontinued production due to high costs. Product plan selection must consider various factors including assembly sequence planning (ASP) and assembly line balancing (ALB), as these affect production efficiency and costs significantly. ASP involves determining the optimal sequence of assembly operations, while ALB focuses on distributing tasks across workstations to minimize idle time and maximize efficiency. Given the complexity and the multiple conflicting objectives in real-world scenarios, advanced techniques such as genetic algorithms (GAs) and multi-objective optimization methods, including the Guided Genetic Algorithm (G-GA) and Weighted Pareto-based Multi-Objective Genetic Algorithm (WPMOGA), are employed to address these challenges. These methods help in finding Pareto optimal solutions that balance cost, time, and resource utilization effectively.

Hamid Yilmaz [35] did the the literature on assembly line balancing (ALB) and multi-manned assembly lines (MMAL) highlights significant advancements in optimizing task allocation and workstation configuration to enhance production efficiency. Traditional ALB focuses on minimizing cycle time or the number of workstations while adhering to precedence constraints (Gökçen et al., 2006). The advent of MMALs, where multiple workers collaborate at each workstation, introduces new dimensions to ALB by potentially reducing production times and work-in-process (Cevikcan et al., 2008). Key studies, such as those by Johnson (1991) and Bukchin & Masin (2004), have explored the integration of specialized teams into ALB, addressing the need for tailored approaches to handle complex assembly tasks. Recent advancements in heuristic and mathematical models, including those by Dimitriadis (2006) and Fattahi et al. (2011), provide robust solutions for balancing and optimizing MMALs, highlighting the evolving nature of this field and the ongoing need for innovative approaches to tackle the challenges of modern assembly line design. Yang Li [36] presented Effective factory layout planning is crucial for enhancing both cost and time efficiency in a competitive manufacturing landscape, where agility is needed to adapt to fluctuating customer demands and diverse product mixes. Well-designed layouts can streamline material handling, minimize transportation times, and reduce production cycle times, ultimately lowering manufacturing costs and boosting operational performance. Discrete Event Simulation (DES) has emerged as a powerful tool in this context, offering a method to model and optimize complex manufacturing systems by simulating material flow and operational dynamics. DES allows for the virtual evaluation of different layout designs before implementation, providing insights into potential bottlenecks and process inefficiencies. This paper demonstrates the application of DES using the Witness simulation environment to compare Straight-line, U-shaped, and Parallel U-shaped layouts, ultimately identifying the Parallel U-shaped layout as the most effective in reducing workforce needs and optimizing production efficiency.

According to Weida Xu [37], the Assembly Line Balancing Problem (ALBP) involves assigning tasks to sequential stations to optimize production efficiency while adhering to constraints. This paper addresses a complex variation of ALBP involving mixed models, fuzzy operation times, and drifting operations, with the objective of minimizing total work overload time. Traditional ALBP approaches typically aim to minimize the number of stations or cycle time under deterministic conditions. However, this research incorporates fuzzy operation times to better reflect real-world uncertainties, such as imprecise estimates of operation durations. The study proposes a fuzzy total work overload time minimization model using chance-constrained programming. To solve this model, a hybrid intelligent algorithm combining fuzzy simulation with genetic algorithms is developed. This approach is designed to handle the complexities of mixed models and variable operation times, and extensive computational results demonstrate its effectiveness in minimizing work overload and improving assembly line performance. Din-Horng Yeh [38] paper introduces a novel heuristic for solving the Assembly Line Balancing Problem (ALBP), which combines bidirectional task assignment with the Critical Path Method (CPM). This approach addresses the challenge of assigning tasks to workstations efficiently by simultaneously creating forward and backward workstations and prioritizing critical tasks identified by CPM. By iteratively assigning tasks and selecting workstations based on slack time, the heuristic aims to minimize the number of workstations needed while respecting task precedence and cycle time constraints. The proposed method shows promising results in terms of efficiency and solution quality, offering a practical alternative to traditional exact methods for large-scale ALBP instances.

Yeo Keun Kim [39] article explores the use of Genetic Algorithms (GAs) to address the Assembly Line Balancing (ALB) problem, which involves assigning tasks to workstations with the goal of optimizing multiple objectives such as minimizing cycle time, reducing the number of workstations, maximizing workload smoothness, and enhancing work relatedness. The ALB problem is NP-hard, making heuristic methods like GAs particularly valuable for solving large-scale instances. The paper presents several key aspects of GA application, including effective representation methods, decoding techniques, repair methods to ensure feasible solutions, and the combination of genetic operators for single-objective problems. For multiple-objective scenarios, the study emphasizes the need for selection schemes that generate diverse, non-dominated solutions. The experimental results show that GAs can be highly effective for ALB problems, providing a robust tool for tackling various optimization goals in assembly line design and management. Luigi Martino [40] said that designing and balancing assembly lines, crucial in industries like automotive and electronics, involves solving the Assembly Line Balancing Problem (ALBP), which is NP-hard due to its combinatorial nature. The classic ALBP focuses on task assignment to workstations while maintaining precedence constraints and optimizing efficiency. However, real-world scenarios often introduce additional complexities such as sequence-dependent setup times, addressed by the General Assembly Line Balancing Problem with Setups (GALBPS). GALBPS requires not only balancing the line but also optimizing the sequence of tasks within each workstation. Recent advancements have improved heuristic approaches for GALBPS, offering more realistic solutions that account for setup times and enhance overall production efficiency.

Patrick Mcmullen [41] introduces an innovative approach to solving the assembly line balancing problem (ALBP) by utilizing ant colony optimization (ACO) techniques to handle complexities such as parallel workstations, stochastic task durations, and mixed-model scenarios. Inspired by the natural behavior of social insects, the proposed methodology aims to optimize task distribution across workstations by mimicking the self-organizing principles observed in ant colonies, such as positive feedback and pheromone-based decision-making. This heuristic approach is evaluated against various other methods, including simulated annealing, through a series of simulated production runs. The results demonstrate that the ant-based methodology is competitive with established heuristics in terms of performance metrics like cycle time, showcasing its potential for effectively addressing complex ALBP scenarios and offering a promising alternative to traditional optimization techniques. Hindriyanto Dwi Purnomo [42] in his paper addresses the Two-Sided Assembly Line Balancing Problem Type II (TALBP-II) with assignment restrictions, focusing on minimizing cycle time while balancing workloads across a set number of workstations. TALBP-II is particularly relevant for reconfiguring existing assembly lines in industries producing large products like trucks and buses. The study introduces a mathematical model incorporating various constraints such as precedence, zoning, distance, synchronous tasks, and resource limitations. It evaluates the effectiveness of two solution methods: Genetic Algorithm (GA) and Iterative First-Fit Rule (IFFR). GA is noted for its flexibility and speed, making it superior in handling complex constraints and large problem spaces, while IFFR offers a simpler, more straightforward approach suitable for initial solutions. The comparative analysis highlights GA's advantages in solution quality and computational efficiency, thereby providing practical insights for optimizing two-sided assembly lines in real-world settings.

Humyun Fuad Rahman [43] said Optimizing material handling is a critical issue in modern assembly line systems. This paper aims to address the combined challenge of balancing a robotic assembly line and scheduling material handling operations, a topic that has seen limited research. With advancements in Industry 4.0 technologies, such as the Internet of Things, big data, and cloud computing, there is a growing focus on achieving full autonomy in manufacturing systems. This involves integrating automated guided vehicles (AGVs) with robotic assembly lines to create reliable and flexible production environments.

Mohd Fadzil Faisae Rashid [44] done the study and introduced introduces a heuristic and metaheuristic-based approach to simultaneously tackle the complexities of assembly line balancing and AGV scheduling, minimizing cycle time and total tardiness. By demonstrating the effectiveness of this integrated decision-making approach, the research offers valuable insights for production managers on designing and optimizing smart assembly systems. Mohd Fadzil Faisae Rashid [44] conveyed that assembly optimisation is crucial in manufacturing, particularly for Assembly Sequence Planning (ASP) and Assembly Line Balancing (ALB), both of which are NP-hard problems. Soft computing approaches, including Genetic Algorithms (GA), Ant Colony Optimisation (ACO), and Particle Swarm Optimisation (PSO), are frequently employed to address these challenges. Despite not guaranteeing optimal solutions, these methods have proven effective in enhancing assembly processes by handling complex constraints and large solution spaces. Recent research emphasizes the integration of assembly optimisation activities throughout various stages of product development, aiming to improve overall efficiency and cost-effectiveness in manufacturing. Abdolreza Roshani [45] extended the Two-Sided Assembly Line Balancing Problem (TALBP) addresses the challenge of efficiently assigning tasks to parallel workstations on both sides of an assembly line for large, high-volume products like automobiles. Unlike traditional single-sided lines, TALBP involves tasks with specific preferences for left or right sides and must account for both precedence constraints and cycle times. The cost-oriented variant of TALBP aims to minimize the total production cost per unit by considering both labor costs, based on task difficulty and wage rates, and capital costs related to the number of workstations. To solve TALBP, exact methods like Mixed-Integer Programming (MIP) and heuristic approaches such as Simulated Annealing (SA) are used, with SA particularly suited for larger, more complex instances.

Abdolreza Roshan [46] said that Mixed-Model Assembly Line (MMAL) balancing problem (MMALBP) involves assigning tasks to multi-manned workstations in a production line designed to handle multiple product models with varying features. This problem is categorized into Single-Model (SMAL) and Mixed-Model (MMAL), with MMAL handling different product variants simultaneously. The primary aim in MMALBP is to minimize the number of workers while also reducing the number of workstations. This study contributes by introducing a new Mixed-Integer Programming (MIP) formulation and a Simulated Annealing (SA) heuristic for solving MMALBP. The MIP formulation prioritizes minimizing workers and workstations, while the SA approach efficiently tackles medium- to large-scale problems. The paper also reviews relevant literature and outlines the problem's assumptions and constraints, including deterministic task durations and fixed workstation capacities. Whereas I. SABUNCUOGLU [47] said that assembly Line Balancing (ALB) is crucial in production management due to its impact on efficiency and cost. Given its NP-hard complexity, heuristic methods are often employed to find practical solutions efficiently. This paper introduces a novel heuristic for the deterministic, single-model ALB problem utilizing a Genetic Algorithm (GA) with a dynamically partitioned chromosome structure. By incorporating elitism and elements from Simulated Annealing (SA), the proposed approach merges advanced AI concepts into a unified framework. Computational tests show that this GA-based method outperforms existing heuristics, demonstrating superior schedule quality and computational efficiency. The paper reviews traditional and GA-based solutions, highlighting the effectiveness of the proposed algorithm in optimizing ALB schedules. ARMIN SCHOLL [48] paper explores heuristics for solving the Simple Assembly Line Balancing Problem (SALBP), focusing on Type 1 (SALBP-1) and Type 2 (SALBP-2). SALBP-1 aims to minimize the number of workstations for a given production rate, while SALBP-2 seeks to maximize the production rate or minimize idle times for a fixed number of stations. We introduce bidirectional and dynamic extensions to heuristic priority rules commonly used for SALBP-1. For SALBP-2, we present iterative search methods that apply SALBP-1 procedures and develop improvement strategies combined with tabu search to overcome local optima. Various tabu search configurations are analyzed, including a nontraditional approach for SALBP-1. Computational experiments validate the effectiveness of these new heuristics, showing improvements over existing methods.

S.A. Seyed-Alagheband [49] extends the traditional assembly line balancing problem by incorporating sequence-dependent setup times between tasks, focusing on the General Assembly Line Balancing Problem with Setups Type II (GALBPS-II). Unlike simpler models, GALBPS-II aims to minimize cycle time while using a fixed number of workstations, a scenario common in optimizing existing assembly lines. The study introduces a mathematical model and a novel simulated annealing (SA) algorithm, optimized through the Taguchi method to enhance efficiency and solution quality. Computational results demonstrate the effectiveness of the proposed SA algorithm in addressing this complex, NP-hard problem by significantly improving both performance and computational time. According to P. Sivasankaran [50] balancing the assembly line in a mass production system is crucial for enhancing productivity. This paper focuses on the Single Model Assembly Line Balancing Problem (SMALBP), which aims to minimize the number of workstations needed while meeting a specified cycle time and maximizing balancing efficiency. Given the combinatorial nature of this problem, finding near-optimal solutions efficiently is challenging. The paper proposes and evaluates four distinct genetic algorithm (GA)-based heuristics designed to address this issue. A factorial experiment was conducted to analyze these heuristics against three factors: problem size, cycle time, and algorithm type. The study highlights the effectiveness of the GA-based methods and provides a comparison to select the most efficient heuristic for solving the SMALBP.

CHAPTER 3: PROCESS LAYOUT OF ASSEMBLY LINE

3.1. Current Process Layouts

3.1.1. Overview

The assembly line is configured in a U-shaped layout designed to maximize efficiency and streamline the production process from initial assembly to final quality assurance. This layout is strategically developed to facilitate a smooth flow of materials and components through 55 integrated production and quality control stations. By employing both manual and automated tasks, the assembly line aims to minimize cycle times and enhance overall productivity. The primary objective is to reduce the cycle time from 16 seconds to 13 seconds through effective line balancing and process optimization.

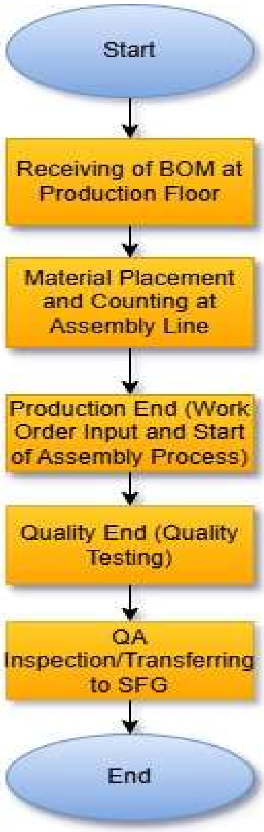

Fig # 1 Flow Chart of Production Floor Assembly Flow Components

3.1.2. Description

The assembly line comprises various workstations, each dedicated to specific tasks, ensuring a seamless transition of components from one stage to the next. Below is a detailed description of each station and its role in the assembly process:

Production End Stations

1. RTI Station (MB Scan): Initial identification and tracking of the motherboard (MB) using a scanning system to ensure proper tracking throughout the production process.

2. Front Camera & Receiver Placement: Installation of the front camera and receiver into the mobile device, aligning components for subsequent assembly stages.

3. Foam Placement: Application of ground foam to critical areas such as the speaker, camera, and motor to provide shock absorption and protect sensitive components.

4. Mic and Vibrator Soldering: Soldering of the microphone and vibrator components onto the motherboard to ensure secure electrical connections.

5. 3-in-1 Component Assembly: Assembly of the speaker, vibrator, and microphone into a single unit before placement onto the motherboard.

6. Side Key FPC and TP FPC Placement: Positioning and connecting of the side key Flexible Printed Circuit (FPC) and the Touch Panel (TP) FPC.

7. Conductive Cloth Application and Coaxial Cable Attachment: Application of conductive cloth for grounding and attachment of the coaxial cable to the motherboard.

8. Main Board and Touch Panel Fixing: Securing the main board to the touch panel, with air pressure used for dust removal and proper alignment.

9. MB Screwing: Manual installation of screws to secure the main board in place.

10. TP Connection: Connecting the touch panel to the motherboard, ensuring proper communication between components.

11. Battery Grounding and Sticker Removal: Application of conductive cloth for battery grounding and removal of the conductive sticker from the battery.

12. Sub Board Attachment: Attaching the sub board to the main board, completing the primary assembly of internal components.

13. Back Camera Placement: Installation of the back camera onto the motherboard.

14. Coaxial Cable Alignment: Aligning the coaxial cable connecting the motherboard and sub board to ensure proper functionality.

15. Mic Rubber Attachment: Attaching the microphone rubber using a fixture to reduce vibrations and noise.

16. Multimeter Test: Performing a continuity test between the battery and motherboard to ensure electrical connectivity.

17. Battery Miller Attachment: Adding a black plastic cover for battery miller attachment, completing the battery assembly process.

18. Back Case Lens Fitting: Fitting the back case lens into the housing with air pressure and pressing to ensure a secure fit.

19. Housing Connection: Attaching the housing to the mobile device to complete the physical assembly.

20. Initial QC and Automated Screwing: Performing initial quality checks and applying screws using automated systems.

21. Fragile Sealing: Application of fragile stickers to secure screws and prevent tampering.

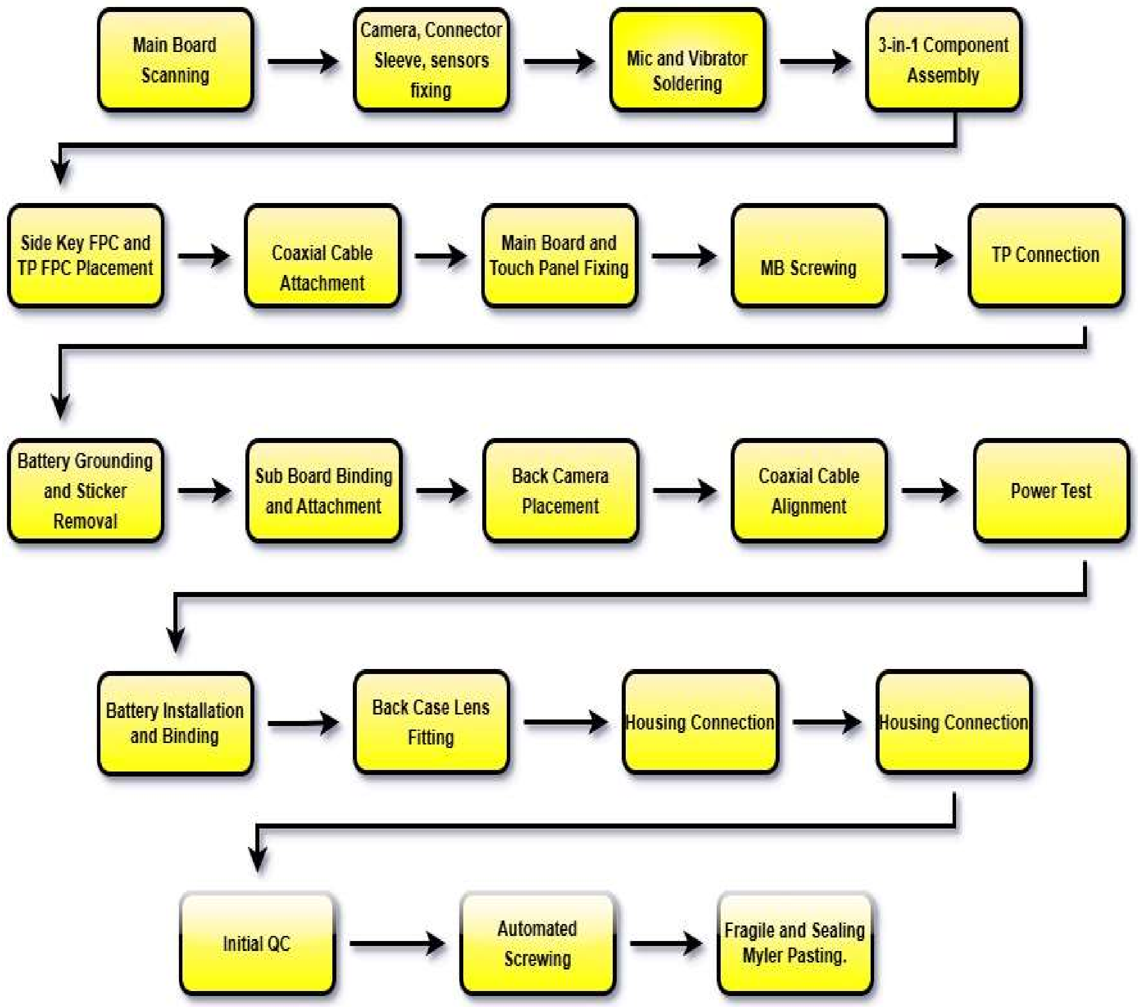

Fig # 2 Detailed Flow Chart of Production End Stations

Quality Control Stations

1. Second Appearance QC: Conducting a thorough quality check to verify the assembled device's functionality and appearance.

2. Battery Installation: Inserting the battery into the device and securing it for final testing.

3. Configuration Testing: Verifying device configuration to ensure proper setup and functionality.

4. Camera Check: Testing camera functionality to ensure clear image capture and proper operation.

5. Version Check: Verifying the version number using a specific code (*#87#) to ensure software compatibility.

6. Color and Spot Check: Checking the screen for color accuracy and spotting any potential issues.

7. Speaker, Receiver, and Vibration Check: Testing the functionality of the speaker, receiver, and vibration mechanisms.

8. Touch Check: Assessing the touch screen's responsiveness and accuracy.

9. 2-Point Check: Performing specific functionality checks to ensure device performance meets standards.

10. Acceleration and Distance Check: Testing light change for acceleration and distance functionality.

11. Charging and Headset Check: Verifying charging functionality and headset compatibility.

12. SD Card & Flash Check: Checking SD card and flashlight functionalities to ensure proper operation.

13. SIM & Bluetooth Check: Verifying SIM card and Bluetooth functionalities.

14. GPS Check: Testing GPS accuracy (minimum 5 stars) and touch panel breakpoints to ensure reliable location services.

15. MMI Scan: Performing a Mobile Manufacturer's Interface (MMI) scan to check device system health.

16. Audio Testing: Assessing audio functionalities to ensure sound quality and performance.

17. Antenna Testing: Checking the antenna performance for signal strength and connectivity.

18. RQC1: Completing the first round of Quality Control to ensure all criteria are met.

19. QA: Final Quality Assurance to confirm the device meets all quality standards before packaging.

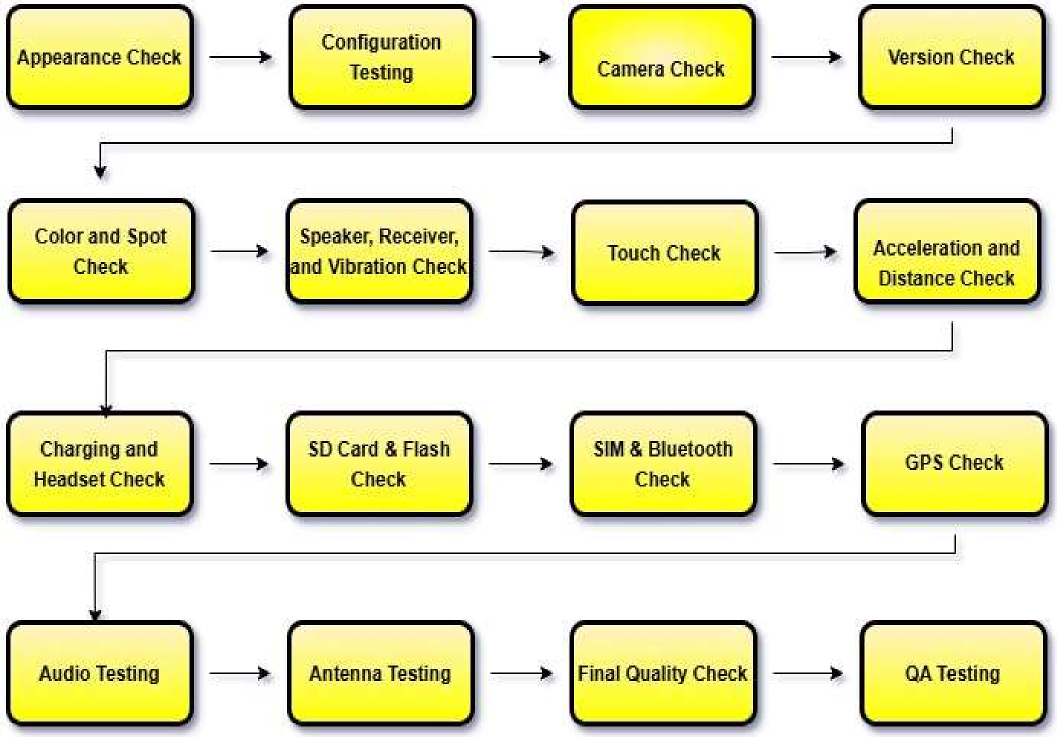

Fig # 3 Detailed Flow Chart of Quality Testing Stations

3.1.3. Components

1. Worker-Operated Stations:

All the stations are operated by workers either for manual task or to perform assembly or quality testing tasks through machines.

2. Machine-Operated Stations:

- Thermal gel Dispensing
- Power Consumption Test Machine
- Automatic Screw Machine
- Audio Testing Machine
- Antenna Testing Machine
- Glue Dispensing Machine

3. Fixtures and Computers:

- Screw Locking Fixture
- Battery Pressing Fixture
- Deco Pressing fixture
- Battery Cover Pressing Fixture
- Camera testing Fixture
- Distance Sensor Testing Fixture
- Dual Camera Testing Fixture

4. Computers

- RTI Input
- Camera Binding
- Small Board Binding
- Power Consumption*4
- Battery Binding
- Man Machine Interface clearance
- Audio Testing*3
- Antenna Testing*4
- Quality Final Testing
- Quality Assurance Testing

5. Cycle Time and Line Balancing:

Current Setup: 117 activities are distributed across 58 stations with a cycle time of 15.75 seconds.

Optimization Goal: Reduce the cycle time to 14 seconds through effective line balancing and optimization to enhance overall efficiency and productivity.

3.1.4. Assembly Process

The assembly process starts with component scanning and progresses through various stages, including:

Component Assembly: Installation and integration of components.

Quality Checks: Initial and final quality inspections to verify product functionality and appearance.

Aging Process: Devices undergo an aging process of up to 8 hours before final testing and packing to ensure stability and reliability.

3.2. Existing Challenges or Inefficiencies

3.2.1. Identified Issues

1. Line Balancing:

Current Challenge: The distribution of tasks across stations is uneven, resulting in bottlenecks and inefficiencies. Some stations are overburdened, while others are underutilized.

Impact: Variability in task completion times affects overall cycle times and throughput, leading to production delays and reduced efficiency.

2. Continuous Improvement:

Current Challenge: There is a need for ongoing enhancements to adapt to evolving production demands and integrate new technologies or methods.

Impact: Stagnation in process improvements can lead to missed opportunities for increasing efficiency and reducing costs.

3. Cost Management:

Current Challenge: Balancing production costs with maintaining high-quality standards is challenging. Optimizing processes to minimize waste and reduce costs is critical.

Impact: High production costs can impact profitability and market competitiveness.

4. Standardization:

Current Challenge: Ensuring consistency in the assembly process across different phone models, which are 90% similar but have 10% differences due to varying functions and components.

Impact: Inconsistent processes can lead to variations in product quality and efficiency, affecting customer satisfaction and production consistency.

5. Lean Manufacturing Principles:

Current Challenge: Implementing lean principles to eliminate waste, reduce cycle times, and improve workflow.

Impact: Ineffective adoption of lean practices results in inefficiencies, increased production times, and missed opportunities for process optimization.

3.2.2. Bottlenecks

1. Station Bottlenecks:

Description: Specific stations may experience delays due to high complexity or workload, disrupting the overall production flow.

Example: Stations with complex assembly tasks or manual handling requirements may become bottlenecks, slowing down the entire line.

2. Machine Downtime:

Description: Unexpected breakdowns or maintenance issues with machines, such as automatic screw machines or power testing machines, can cause interruptions.

Impact: Machine downtime leads to production delays and decreased throughput.

3. Material Flow Issues:

Description: Inefficiencies in material flow, including delays in material replenishment or handling, can disrupt production.

Impact: Disruptions in material flow result in idle time and reduced efficiency.

3.2.3. Inefficiencies

- Excessive Waiting Times
- Unbalanced Workloads
- Variability in Task Execution

3.2.4. Impact of Inefficiencies

1. Efficiency and Effectiveness:

Impact of Challenges: The identified challenges affect the assembly line's efficiency and effectiveness by increasing cycle times, causing production delays, and reducing overall throughput.

Cost Implications: Inefficiencies and unbalanced workloads contribute to higher production costs and lower profitability.

2. Quality and Consistency:

Impact of Standardization Issues: Inconsistent processes across different models can lead to variations in product quality, affecting customer satisfaction and brand reputation.

Impact of Insufficient Lean Practices: Incomplete implementation of lean principles results in wasted resources, increased cycle times, and missed opportunities for optimization.

3. Continuous Improvement:

Impact of Lack of Continuous Improvement: Without ongoing enhancements, the production process may become outdated, limiting the ability to adapt to new challenges and opportunities for improvement.

CHAPTER 4: LINE BALANCING AND WORK FLOW ENHANCEMENT

4.1. Introduction to Line Balancing Techniques

4.1.1. Overview

Line balancing is fundamental to manufacturing efficiency as it directly impacts how effectively resources are utilized, costs are controlled, and production targets are met. By optimizing the allocation of tasks, adhering to constraints, and adapting to modern manufacturing challenges, line balancing ensures a streamlined, cost-effective, and flexible production process. Advances in algorithms and techniques continue to enhance the ability of manufacturers to address diverse and complex production scenarios, further underscoring the significance of line balancing in achieving operational excellence.

4.1.2. Techniques Evaluated

1. Longest Operation Time (LOT)

The Longest Operation Time technique involves assigning tasks with the longest processing times first. The rationale is that tasks with longer times are more likely to create bottlenecks if left until later in the process.

2. Most Following Tasks (MFT)

Description:

The Most Following Tasks technique prioritizes tasks that have the most number of subsequent tasks or dependencies. This approach is based on the idea that tasks which are critical for many subsequent tasks should be handled first to avoid cascading delays.

2. Ranked Positional Weight (RPW)

The Ranked Positional Weight method assigns tasks based on a weighted ranking that considers both the task's own time and the times of tasks that follow it. Tasks are ranked according to their positional weight, which includes the task time and the cumulative time of all tasks that follow it.

4. Shortest Operating Time (SOT)

The Shortest Operating Time technique prioritizes tasks with the shortest processing times. The idea is to quickly complete smaller tasks, potentially leaving more time to handle larger tasks later.

5. Fewest Following Tasks (FFT)

The Fewest Following Tasks technique focuses on assigning tasks that have the fewest number of subsequent tasks first. The goal is to address tasks that have minimal dependencies early on to avoid complications with task sequencing later.

4.2. Initial Line Balancing Sheet

The initial line balancing sheet provides a comprehensive overview of the assembly line's configuration and performance metrics.

Workstations and Tasks: The assembly line now operates with a total of 58 workstations, each assigned specific functions to contribute to the final product. This configuration reflects an adjustment in the number of workstations to better distribute the tasks and improve workflow.

Task Times: The cycle time for the assembly line is updated to 15.75 seconds. This cycle time indicates the duration required to complete one production cycle. The total time allocated for production per cycle is 913.5 seconds, whereas the time needed to produce each unit is 677.25 seconds.

Task Distribution: The tasks are distributed across the 58 workstations, adjusting from the initial 49 workstations. This adjustment aims to enhance workload distribution and minimize bottlenecks. The line efficiency, calculated as the ratio of time needed to allocated time, is currently 74.14%, while the balance delay is at 25.86%.

Cycle Time: The cycle time for the assembly line is set at 15.75 seconds. This cycle time represents the duration needed to complete one full production cycle. The total time available for production aligns with the shift capacity, ensuring that the production requirements are met.

Capacity Metrics: The updated capacity metrics reflect the changes in the assembly line configuration. The assembly line's capacity per hour is 228.57 units, and the capacity per shift is 1668.57 units. This is based on the man power of 58 operators and an Units Per Person Hour (UPPH) rate of 3.94.

Idle Time: The idle time per cycle has been calculated at 236.25 seconds, indicating the period during which workstations are not utilized due to imbalances in task distribution.

Initial Line Balancing Sheet		
Work Station No	**Task Name**	**Process Standard Time (S)**
1	Scan MES code, Paste it, Stick waterproof label and Paste screen connector film	11.50
2	Take 50M silicone film after pasting and 16M front buckle	8.95
3	50M conductive after pasting, 50M rear buckle and Bind Camera	10.25
4	Install the rear camera bracket, rear camera conductive, rear camera hard foam	9.40
5	8W rear camera, 2M rear camera	13.00
6	Distance sensor sleeve and Motherboard point thermal gel	10.20
7	Three-in-one protective cover installation and remove screen FPC blue film here	7.70
8	Attached to the side button FPC	7.55

9	Install the speaker and stick the earpiece conductive cloth	10.50
10	F. cam rubber	8.00
11	MB install, inspection	11.50
12	Lock the motherboard screws and Front Camera Copper Foil	13.50
13	Assemble the top support bracket components, paste the waterproof Mylar	11.80
14	Paste the graphite sheet of the main board and 2 stick screen connector film	11.40
15	waterproof label over SB earphone holder rubber sleeve, USB rubber sleeve	10.75
16	Install the small board, bind the small board, and drive the small board screw*1	9.80
17	Coaxial connect, battery blue film tear off	10.30
18	Align coaxial cable	7.50
19	Install the main FPC	10.56
20	Button screen FPC and main FPC	9.20
21	Install the Speaker, install the speaker bracket, hit the speaker bracket screw	8.60
22	Power Consumption Test	9.16
23	Key material binding and battery assembly	10.50
24	Battery & BTB & side button secondary pre-compression, button battery BTB	10.80
25	The motor is equipped with conductive cloth, and attached to the middle frame	11.00
26	Middle frame is equipped with FPM and buckle FPM BTB and remove cam film	11.00
27	After installation, 2M camera rubber sleeve*, 8W silicone sleeve	7.00
28	1st Appearance	13.00
29	Install the middle frame	10.50

30	Paste NFC Mylar, install whole phone cover	9.72
31	Lock the middle frame screw (AUTOMATIC SCREW MACHINE)	8.57
32	Manual Screw lock	9.19
33	Attach screws water Mylar, attach decorative pieces to foam	7.30
34	Attach adhesive for post-photo lens	4.33
35	Attach Camera Deco 1 and lens for decoration	13.50
36	Equipped with rear-camera lenses	10.30
37	Equipped with rear-camera decoration	8.18
38	Rear-camera deco and lenses are pressed together with Horn heat dissipation film	11.40
39	PAL and Fragile	10.30
40	2nd Appearance	10.41
41	Configuration	11.32
42	Brightness Far Cam+Storage+Double Tap	13.00
43	Camera + Fixture + Version	14.22
44	Backlight Test + Color + Key + Mic + Speaker	15.50
45	Camera + PCR + Touch	10.44
46	Charging	13.50
47	Earphone+ FM +WIFI + Bluetooth	15.00
48	Insert SIM tray + SIM Test + Storage+ eject SIM tray	13.50
49	OTG + PS Calibration + LS Calibration	13.00
50	Gravity + Drive + Distance + Light + Acceleration + Gyro	14.00

51	GPS + Dual SIM + Test Report + MMI + Remove Silicon Cover	15.75
52	Audio	11.28
53	Antenna	13.08
54	Middle frame dispensing	10.03
55	Cover plate manually pressing	11.67
56	The battery cover is pre-pressed on the whole surface	10.44
57	RQC	8.39
58	Pink Pouches	7.61

Table 1 Initial Line Balance Sheet

Components	Initial ALB Results
Cycle time (seconds)	15.75
Min (theoretical) # of stations	43
Actual # of stations	58
Time allocated (Seconds/Cycle)	913.5
Time needed (Seconds/unit)	677.25
Idle time (Seconds/cycle)	236.25
Efficiency (needed/allocated)	74.14%
Balance Delay	25.86%

Man Power	58
UPPH	3.94
Capacity Per Hour	228.57
Capacity Per Shift	1668.57

Table 2 Production Capacity as Per Initial Line Balance Sheet

The provided metrics highlight the current efficiency and capacity of the assembly line, offering insights into potential areas for improvement. By analyzing these details, it becomes possible to optimize task distribution, enhance line balancing, and achieve a more effective and productive manufacturing process.

4.3. Implementation of Line Balancing Techniques

4.3.1. Implementation of Longest Operation Time (LOT)

Components	Longest Operation Time (LOT)
Cycle time (seconds)	14
Min (theoretical) # of stations	48
Actual # of stations	55
Time allocated (Seconds/Cycle)	770
Time needed (Seconds/unit)	672
Idle time (Seconds/cycle)	98
Efficiency (needed/allocated)	87.27%
Balance Delay	12.73%

Man Power	55
UPPH	4.68
Capacity Per Hour	257.14
Capacity Per Shift	1877.14

Table 3 Production Capacity After LOT Implementation

In this production setup, each cycle lasts 14 seconds, an improvement from the previous cycle time of 15.75 seconds, despite operating with more workstations and workers. The theoretical minimum number of workstations required is 48, but 55 stations are actually utilized, reflecting a comprehensive approach to task distribution. The allocated time per cycle is 770 seconds, while the actual time needed per unit is 672 seconds, resulting in 98 seconds of idle time per cycle. The system maintains a strong efficiency of 87.27% with a balance delay of 12.73%, indicating some minor inefficiencies in task distribution. With 55 workers, the production system achieves a capacity of 257.14 units per hour and 1877.14 units per shift, demonstrating a significant improvement in performance compared to previous metrics.

4.3.2. Implementation Most Following Tasks (MFT)

Components	**Most Following Tasks (MFT)**
Cycle time (seconds)	14
Min (theoretical) # of stations	48
Actual # of stations	60
Time allocated (Seconds/Cycle)	840
Time needed (Seconds/unit)	672

Idle time (Seconds/cycle)	168
Efficiency (needed/allocated)	80.00%
Balance Delay	20.00%
Man Power	33
UPPH	4.29
Capacity Per Hour	257.14
Capacity Per Shift	1877.14

Table 4 Production Capacity After MFT Implementation

In this production setup, each cycle lasts 14 seconds, which is slightly longer than previous cycle times, despite utilizing more workstations and workers. The theoretical minimum number of workstations required is 48, but 60 stations are actually employed, reflecting a thorough approach to task distribution. The allocated time per cycle is 840 seconds, while the actual time needed per unit is 672 seconds, resulting in 168 seconds of idle time per cycle. The system maintains an efficiency of 80.00% with a balance delay of 20.00%, indicating some inefficiencies in task distribution. With 33 workers, the production system achieves a capacity of 257.14 units per hour and 1877.14 units per shift, showing a stable performance level with a slight decrease in output compared to previous metrics.

4.3.3. Implementation Ranked Positional Weight (RPW)

Components	Ranked Positional Weight (RPW)
Cycle time (seconds)	14
Min (theoretical) # of stations	48
Actual # of stations	59

Time allocated (Seconds/Cycle)	826
Time needed (Seconds/unit)	672
Idle time (Seconds/cycle)	154
Efficiency (needed/allocated)	81.36%
Balance Delay	18.64%
Man Power	33
UPPH	4.36
Capacity Per Hour	257.14
Capacity Per Shift	1877.14

Table 5 Production Capacity After RPW Implementation

In this production setup, each cycle lasts 14 seconds, consistent with previous cycle times, even though more workstations and workers are now in use. The theoretical minimum number of workstations required is 48, but 59 stations are actually utilized, reflecting a well-considered approach to distributing tasks. The allocated time per cycle is 826 seconds, while the actual time needed per unit is 672 seconds, resulting in 154 seconds of idle time per cycle. The system maintains an efficiency of 81.36% with a balance delay of 18.64%, indicating some inefficiencies in task distribution. With 33 workers, the production system achieves a capacity of 257.14 units per hour and 1877.14 units per shift, demonstrating a stable performance with slight improvements in output compared to previous metrics.

4.3.4. Implementation Shortest Operating Time (SOT)

Components	Shortest Operating Time (SOT)
Cycle time (seconds)	14

Min (theoretical) # of stations	48
Actual # of stations	67
Time allocated (Seconds/Cycle)	938
Time needed (Seconds/unit)	672
Idle time (Seconds/cycle)	266
Efficiency (needed/allocated)	71.64%
Balance Delay	28.36%
Man Power	33
UPPH	3.84
Capacity Per Hour	257.14
Capacity Per Shift	1877.14

Table 6 Production Capacity After SOT Implementation

In this production setup, each cycle lasts 14 seconds, maintaining consistency with previous cycle times, even with an increase in the number of workstations and workers. The theoretical minimum number of workstations required is 48, but 67 stations are actually used, reflecting a comprehensive approach to task distribution. The allocated time per cycle is 938 seconds, while the actual time needed per unit is 672 seconds, resulting in 266 seconds of idle time per cycle. The system shows an efficiency of 71.64% with a balance delay of 28.36%, indicating significant inefficiencies in task distribution. With 33 workers, the production system achieves a capacity of 257.14 units per hour and 1877.14 units per shift, demonstrating stable output levels despite the increased number of workstations.

4.3.5. Implementation Fewest Following Tasks (FFT)

Components	**Fewest Following Tasks (FFT)**
Cycle time (seconds)	14
Min (theoretical) # of stations	48
Actual # of stations	64
Time allocated (Seconds/Cycle)	896
Time needed (Seconds/unit)	672
Idle time (Seconds/cycle)	224
Efficiency (needed/allocated)	75.00%
Balance Delay	25.00%
Man Power	33
UPPH	4.02
Capacity Per Hour	257.14
Capacity Per Shift	1877.14

Table 7 Production Capacity After FFT Implementation

In this production setup, each cycle lasts 14 seconds, consistent with previous cycle times, despite an increase in the number of workstations and workers. The theoretical minimum number of workstations required is 48, but 64 stations are utilized, indicating a thorough approach to distributing tasks. The allocated time per cycle is 896 seconds, while the actual time needed per unit is 672 seconds, resulting in 224 seconds of idle time per cycle. The system maintains an efficiency of 75.00% with a balance delay of 25.00%, reflecting some inefficiencies in task distribution. With 33 workers, the production system achieves a capacity of 257.14 units per hour and 1877.14 units per shift, showing stable performance with a slight decrease in output efficiency compared to previous metrics.

4.4. Effectiveness of longest Operating Time Rule

The Longest Operating Time (LOT) Rule emerges as the most effective heuristic among those considered, demonstrating superior performance in minimizing idle time and balancing workflow. Despite some challenges in practical implementation, such as alignment issues and non-value-added delays, LOT excels by prioritizing tasks based on their longest duration, which significantly reduces overall cycle idle time. Necessary adjustments were made to align with the LOT technique, including refining task allocations and addressing process inefficiencies to achieve the final, most effective setup for line balancing. This comprehensive approach optimized station usage, tackled bottlenecks early, and enhanced throughput. Consequently, the production system realized better resource utilization, higher throughput rates, and significantly improved operational performance compared to other scheduling heuristics, validating LOT as the optimal choice for balancing and optimizing production lines.

Components	Initial ALB Results	Longest Operation Time (LOT)	Most Following Tasks (MFT)	Ranked Positional Weight (RPW)	Shortest Operating Time (SOT)	Fewest Following Tasks (FFT)
Cycle time (seconds)	15.75	14	14	14	14	14
Min (theoretical) # of stations	43	48	48	48	48	48
Actual # of stations	58	55	60	59	67	64
Time allocated (Seconds/Cycle)	913.5	770	840	826	938	896
Time needed (Seconds/unit)	677.25	672	672	672	672	672
Idle time (Seconds/cycle)	236.25	98	168	154	266	224
Efficiency (needed/allocated)	74.14%	87.27%	80.00%	81.36%	71.64%	75.00%
Balance Delay	25.86%	12.73%	20.00%	18.64%	28.36%	25.00%
Man Power	58	55	33	33	33	33

UPPH	3.94	4.68	4.29	4.36	3.84	4.02
Capacity Per Hour	228.57	257.14	257.14	257.14	257.14	257.14
Capacity Per Shift	1668.57	1877.14	1877.14	1877.14	1877.14	1877.14

Table 8 Effectiveness of LOT Over Other Techniques

4.5. Optimized Line Balancing Sheet

4.5.1. Line Balance Sheet Transitioned from combined Task to Individual Activities

The production line has been optimized by breaking down each task into individual activities to gain a detailed understanding of the specific time required for each step. This approach has been crucial for setting accurate predecessors and dependencies, ensuring that each activity follows the correct sequence and integrates seamlessly with others. Dividing tasks into these smaller, manageable activities allows for precise scheduling and coordination, providing a clearer picture of the workflow and enhancing the ability to optimize the production process effectively.

By defining specific predecessors for each activity, this method ensures that each step in the production process is completed in the right order, which is vital for maintaining the continuity and efficiency of the workflow. Examining each activity in detail also facilitates the identification and addressing of potential inefficiencies and bottlenecks. This approach supports better resource management by allocating time and effort based on the specific requirements of each step, while minimizing idle time by aligning each activity with its predecessor, thus maintaining a continuous and efficient production flow. Additionally, this refined methodology enables real-time adjustments and improves adaptability to changes in production demands. By meticulously tracking each activity's progress and its impact on subsequent tasks, the process can be dynamically optimized to respond to unexpected issues or shifts in priorities.

Task Name	Activity Description	Activity No
	Scan MB MES code and Paste it	1

Scan MES code and Paste it, Stick waterproof label and Paste screen connector film	Stick waterproof label	2
	Paste screen connector film	3
Take 50M silicone film after pasting and 16M front buckle	Take 50M silicone film and paste it	4
	After pasting buckle 16M front camera	5
50M conductive after pasting, 50M rear buckle and Bind Camera	Paste 50M conductive	6
	Bind 50M rear camera	7
	Buckle 50M rear camera	8
Install the rear camera bracket, rear camera conductive, rear camera hard foam	Install the rear camera bracket	9
	Paste rear camera conductive	10
	Paste rear camera hard foam	11
8W rear camera, 2M rear camera	Install 8W rear camera	12
	Install 3M rear camera	13
Distance sensor sleeve and Motherboard point thermal gel	Install distance sensor sleeve	14
	Draw motherboard point thermal gel	15
Three-in-one protective cover installation and remove screen FPC blue film here	Three-in-one protective cover installation	16
	Remove screen FPC blue film	17
Attached to the side button FPC	Attached to the side button FPC	18
Install the speaker and stick the earpiece conductive cloth	Install the speaker	19
	Stick the earpiece conductive cloth	20
F. cam rubber	Install F. cam rubber	21
MB install, inspection	Install Main Board	22

	Inspection of MB	23
Lock the motherboard screws and Front Camera Copper Foil	Lock the motherboard screws	24
	Paste Front Camera Copper Foil	25
Assemble the top support bracket components, paste the waterproof Mylar	Assemble the top support bracket components	26
	Paste the waterproof Mylar	27
Paste the graphite sheet of the main board and 2 stick screen connector film	Paste the graphite sheet of the main board	28
	Paste 2 stick screen connector film	29
Small board with waterproof label, earphone holder rubber sleeve, USB rubber sleeve	Paste waterproof label over small board	30
	Fix earphone holder rubber sleeve	31
	Fix USB rubber sleeve	32
Install the small board, bind the small board, and drive the small board screw*1	Install the small board	33
	Bind the small board,	34
	Drive the small board screw*1	35
Coaxial connect, battery blue film tear off	Connect Coaxial cable	36
	Tear off Battery blue film	37
Align coaxial cable	Align coaxial cable	38
Install the main FPC	Install the main FPC	39
Button screen FPC and main FPC	Buckle screen FPC	40
	Buckle main FPC	41
Install the Speaker, install the speaker bracket, hit the speaker bracket screw	Install the Speaker	42
	Install the speaker bracket	43
	Lock the speaker bracket screw	44

Power Consumption Test	Power Consumption Test	45
Key material binding and battery assembly	Battery binding	46
	Battery Assembling	47
Battery & BTB & side button secondary pre-compression, button battery BTB	Battery connector buckling	48
	Battery & BTB & side button compression	49
The motor is equipped with conductive cloth, and attached to the middle frame	Equip the vibratory motor with conductive cloth	50
	Attached the motor to the middle frame	51
The middle frame is equipped with fingerprint and buckle fingerprint BTB and camera film are removed here	The middle frame is equipped with fingerprint	52
	Buckle fingerprint BTB	53
	Remove the Camera film	54
After installation, 2M camera rubber sleeve*, 8W silicone sleeve	Fix 2M camera rubber sleeve	55
	Fix 8W silicone sleeve	56
1st Appearance	1st Appearance	57
Install the middle frame	Install the middle frame	58
Paste NFC Mylar, install whole phone cover	Paste NFC Mylar	59
	Install whole phone cover	60
Lock the middle frame screw (AUTOMATIC SCREW MACHINE)	Automatic Screw Locking	61
Manual Screw lock	Manual Screw lock	62
Attach screws to prevent heatstroke water Mylar, attach decorative pieces to foam	Attach screws to prevent heatstroke water Mylar	63
	Attach decorative pieces to foam	64
Attach adhesive for post-photo lens	Attach adhesive for post-photo lens	65

Attach Camera Deco 1 and lens for decoration	Attach Camera Deco 1 and lens for decoration	66
Equipped with rear-camera lenses	Equipped with rear-camera lenses	67
Equipped with rear-camera decoration	Equipped with rear-camera decoration	68
Rear-camera decorations and rear-camera lenses are pressed together with Horn heat dissipation film	Pressing of Rear-camera decorations and lenses	69
PAL and Fragile	PAL and Fragile	70
2nd Appearance	2nd Appearance	71
Configuration	Configuration	72
Brightness Far Cam+Storage+Double Tap	Brightness	73
	Far Cam	74
	Storage	75
	Double Tap	76
Camera + Fixture + Version	CEC	77
	Code Dialing	78
	Version Check	79
Backlight Test + Color + Key + Mic + Speaker	Backlight Test	80
	Color	81
	Key	82
	Mic	83
	Speaker	84
Camera + PCR + Touch	Camera	85

	PCR	86
	Touch	87
Charging	Charging	88
Earphone+ FM +WIFI + Bluetooth	Earphone	89
	FM	90
	WIFI	91
	Bluetooth	92
Insert SIM tray + SIM Test + Storage+ eject SIM tray	Insert SIM tray	93
	SIM Test	94
	Storage	95
	eject sim tray	96
OTG + PS Calibration + LS Calibration	OTG	97
	PS Calibration	98
	LS Calibration	99
Gravity + Drive + Distance + Light + Acceleration + Gyro	Gravity	100
	Drive	101
	Distance	102
	Light	103
	Acceleration	104
	Gyro	105
	GPS	106

GPS + Dual SIM + Test Report + MMI + Remove Silicon Cover	Dual cam	107
	Test Report	108
	MMI	109
	Remove Silicon Cover	110
Audio	Audio	111
Ant	Ant	112
Middle frame dispensing	Middle frame dispensing	113
Cover plate manually pressing	Cover plate manually pressing	114
The battery cover is pre-pressed on the whole surface	The battery cover is pre-pressed on the whole surface	115
RQC I	RQC I	116
Pink Pouches	Pink Pouches	117

Table 9 Line Balance Sheet Transitioned in to Individual Activities

4.5.2. Optimized Line Balance Sheet

Each task from the initial line balancing sheet was dissected into discrete activities to gain a clearer understanding of the time required for each step. This granularity allowed for accurate setting of predecessors and dependencies, ensuring a smooth workflow. For instance, tasks such as "Scan MES code and Paste it" were broken down into steps like scanning the code, sticking a waterproof label, and pasting a screen connector film. This detailed approach was crucial for precise scheduling and resource allocation, facilitating better task sequencing and integration.

Following the task breakdown, the Longest Operating Time (LOT) rule was applied, one of five-line balancing techniques used to further refine the production process. The LOT rule, which prioritizes tasks based on their duration, was found to be the most effective in reducing idle time and improving efficiency. It optimized station usage by addressing bottleneck tasks early in the workflow. However, practical implementation revealed some challenges, such as alignment issues and station were aligned with activities together that couldn't been practically possible, which were subsequently addressed. Adjustments were made to the initial optimization plan to accommodate these issues, leading to a final setup that combined the strengths of the LOT rule with necessary modifications to address practical constraints.

The resulting production line optimization not only improved overall efficiency but also enhanced the ability to manage resources effectively and maintain a continuous workflow. The final system demonstrated significant gains in productivity, demonstrating the effectiveness of the detailed task analysis and optimization techniques employed.

OPTIMIZED LINE BALANCE SHEET

Station No.	Activities	Predecessor	Process Time
1	Scan MB MES code and Paste it	1	4.95
	Take 50M silicone film and paste it	4	4.95
	After pasting buckle 16M front camera	5	4
2	Stick waterproof label	2	2.75
	Paste screen connector film	3	3.8
	Paste 50M conductive	6	2.75
	Install the rear camera bracket	9	3.8
3	Paste rear camera conductive	10	2.75
	Paste rear camera hard foam	11	2.85
	Bind 50M rear camera	7	3.5
	Buckle 50M rear camera	8	4

4	Install 8W rear camera	12	6.5
	Install 3M rear camera	13	6.5
5	Install distance sensor sleeve	14	5.55
	Draw motherboard point thermal gel	15	10.2
6	Three-in-one protective cover installation	16	3.5
	Remove screen FPC blue film	17	4.2
	Install the speaker	19	6
7	Stick the earpiece conductive cloth	20	4.5
	Attached to the side button FPC	18	7.55
8	Install F. cam rubber	21	8
9	Inspection of MB	23	4
	Install Main Board	22	7.5
10	Paste Front Camera Copper Foil	25	6
	Lock the motherboard screws	24	7.5
11	Assemble the top support bracket components	26	6.7
	Paste the waterproof Mylar	27	5.1
12	Paste the graphite sheet of the main board	28	5.1
	Paste 2 stick screen connector film	29	6.3
13	Paste waterproof label over small board	30	2.75
	Fix earphone holder rubber sleeve	31	3.8
	Fix USB rubber sleeve	32	4.2

14	Install the small board	33	3.3
	Bind the small board,	34	3.5
	Drive the small board screw*1	35	3
15	Connect Coaxial cable	36	7
	Buckle screen FPC	40	4.2
16	Tear off Battery blue film	37	3.3
	Align coaxial cable	38	7.5
17	Install the main FPC	39	9.56
18	Buckle main FPC	41	5
	Install the Speaker	42	2.5
	Install the speaker bracket	43	3
	Lock the speaker bracket screw	44	3.1
19	Power Consumption Test	45	9.16
20	Battery binding	46	4
	Battery Assembling	47	6.5
21	Battery connector buckling	48	2
	Battery & BTB & side button compression	49	10.8
22	Equip the vibratory motor with conductive cloth	50	5.4
	Attached the motor to the middle frame	51	5.6
23	The middle frame is equipped with fingerprint	52	4.5
	Buckle fingerprint BTB	53	3

	Remove the Camera film	54	3.5
24	Fix 2M camera rubber sleeve	55	3.5
	Fix 8W silicone sleeve	56	3.5
25	1st Appearance	57	13
26	Install the middle frame	58	10.5
27	Paste NFC Mylar	59	7.72
	Install whole phone cover	60	2
28	Automatic Screw Locking	61	8.57
29	Manual Screw lock	62	9.19
30	Attach screws to prevent heatstroke water Mylar	63	3.3
	Attach decorative pieces to foam	64	4
	Attach adhesive for post-photo lens	65	4.33
31	Attach Camera Deco 1 and lens for decoration	66	13.2
32	Equipped with rear-camera lenses	67	10.3
33	Equipped with rear-camera decoration	68	8.18
34	Pressing of Rear-camera decorations and lenses	69	11.4
35	PAL and Fragile	70	10.3
36	2nd Appearance	71	10.41
37	Configuration	72	11.32
38	Brightness	73	3
	Far Cam	74	4.5

	Storage	75	3.5
	Double Tap	76	2
39	CEC	77	8
	Code Dialing	78	3
	Version Check	79	3
40	Charging	88	13.2
41	Camera	85	8
	FM	90	6
42	Drive	101	2
	Light	103	2
	OTG	97	5
	PCR	86	4
43	Touch	87	4
	Earphone	89	4
	Storage	95	4
	Backlight Test	80	2
44	PS Calibration	98	4
	LS Calibration	99	4
	Key	82	2.5
	Distance	102	3
45	Gyro	105	3

	Mic	83	2.5
	Gravity	100	2
	Speaker	84	3
	Bluetooth	92	2.5
46	Insert SIM tray	93	4
	SIM Test	94	3.5
	eject sim tray	96	2
	Acceleration	104	2
47	Color	81	5.5
	WIFI	91	2.5
	GPS	106	4.5
48	Dual cam	107	7.5
	Test Report	108	2.5
	MMI	109	3.25
49	Remove Silicon Cover	110	2.5
	Audio	111	11.28
50	Ant	112	13.08
51	Middle frame dispensing	113	10.03
52	Cover plate manually pressing	114	11.67
53	The battery cover is pre-pressed on the whole surface	115	10.44
54	RQC I	116	8.39

55	Pink Pouches	117	7.61

Table 10 Optimized Line Balance sheet

4.6. Summary and Conclusion

The optimization of the production line has led to substantial improvements in efficiency and productivity. Here are the key outcomes and observations from the optimization process:

1. **Initial Assessment and Task Division:** The drafting of the initial line balance sheet identified key areas for improvement. By breaking down combined tasks into specific activities and assigning predecessors, we created a more granular and manageable workflow.
2. **Application of Line Balancing Techniques:** Implementing all five-line balancing techniques, with a focus on the Longest Operating Time (LOT) rule, was critical in optimizing the production line. Although LOT proved to be the most effective, practical constraints required further adjustments. These were addressed by adapting the general process and assembly understanding to fit real-world conditions.
3. **Final Adjustments and Balance Sheet:** The final balance sheet reflected these adjustments, incorporating both theoretical and practical considerations to refine the workflow.
4. **Performance Metrics:** The results of the optimization are notable:

   In summary, the optimization efforts have led to a more balanced, efficient, and productive production line. The refined process not only reduced cycle times and idle periods but also enhanced overall efficiency and output capacity. Future considerations should include ongoing monitoring and potential further adjustments to maintain and build upon these improvements.

Components	**Currently Running**	**Longest Operation Time (LOT)**	**Improvement**	
Cycle time (seconds)	15.75	14	Reduced by	11%
Min (theoretical) # of stations	43	48	Increased by	12%
Actual # of stations	58	55	Reduced by	5%
Time allocated (Seconds/Cycle)	913.5	770	Reduced by	16%
Time needed (Seconds/unit)	677.25	672	Reduced by	1%
Idle time (Seconds/cycle)	236.25	98	Reduced by	59%
Efficiency (needed/allocated)	74.14%	87.27%	Increased by	18%
Balance Delay	25.86%	12.73%	Reduced by	51%
Man Power	58	55	Reduced by	5%
UPPH	3.94	4.68	Increased by	19%
Capacity Per Hour	228.57	257.14	Increased by	13%
Capacity Per Shift	1668.57	1877.14	Increased by	13%

Table 11 Capacity Optimization

CHAPTER 5: OPERATIONAL IMPACT OF LINE BALANCING

5.1. Introduction

5.1.1. Purpose

This chapter aims to assess the impact of line balancing improvements on overall production efficiency. The focus is on evaluating how implementing the Longest Operating Time (LOT) rule has affected various aspects of production, including effisciency, workflow, and resource utilization.

5.1.2. Scope

The analysis covers:

- **Pre- and Post-Implementation Metrics:** Comparison of production efficiency metrics before and after applying the LOT rule.
- **Workstation Efficiency:** Assessment of changes in workstation efficiency resulting from task reallocation.
- **Bottleneck Reduction:** Evaluation of how line balancing has reduced bottlenecks and improved workflow.
- **Resource Utilization:** Review of changes in labor and equipment usage.
- **Overall Impact:** Summary of performance improvements and any remaining challenges.

5.2. Pre- and Post-Implementation Metrics

The application of the LOT rule has led to significant improvements in production efficiency. Key metrics were analyzed to determine the effectiveness of these changes.

5.2.1. Cycle Time and Throughput

- **Cycle Time:** Reduced from 15.75 seconds to 14 seconds, marking an 11% improvement.

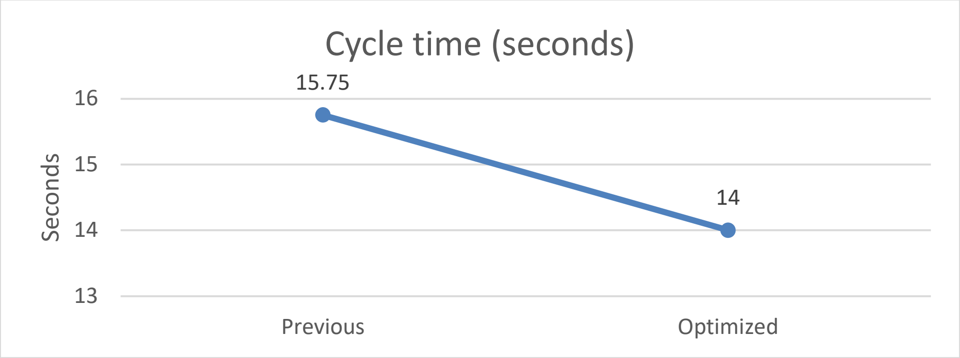

Figure 4 - Graph 1 Previous Vs Optimized Cycle Time

- **Throughput:** Increased capacity per hour from 228.57 units to 257.14 units (13% improvement) and capacity per shift from 1668.57 units to 1877.14 units (13% improvement).

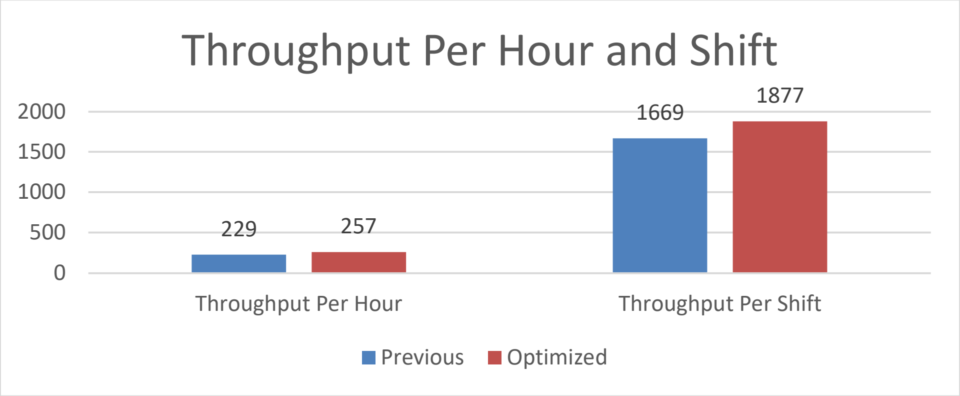

Figure 5 - Graph 2 Previous Vs Optimized Throughput

5.2.2. Impact on Workstation Efficiency

The reallocation of tasks and reduction in the number of workstations have positively impacted workstation efficiency. By addressing idle times and optimizing task sequences, the workflow has become more streamlined.

- **Time Allocated:** Reduced from 913.5 seconds per cycle to 770 seconds, a 16% decrease.

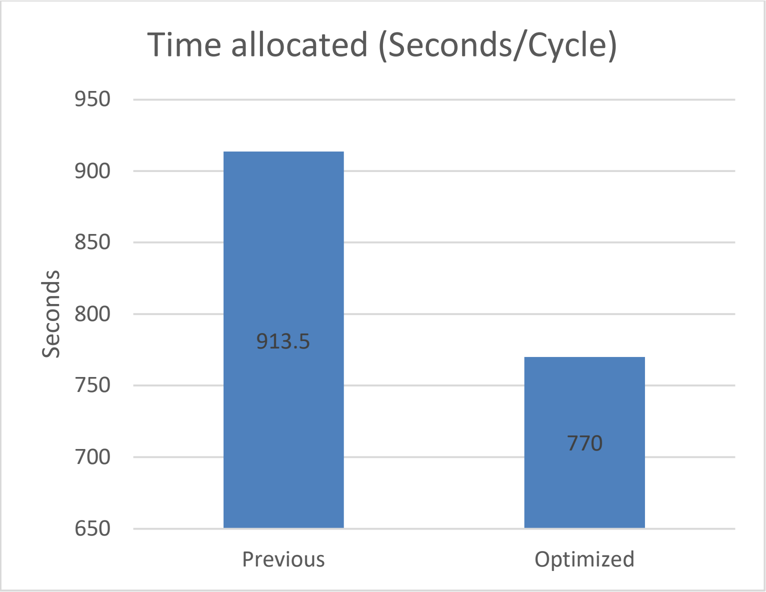

Figure 6 - Graph 3 Previous Vs Optimized Time Allocated

- **Idle Time:** Significantly reduced from 236.25 seconds per cycle to 98 seconds, a 59% reduction.

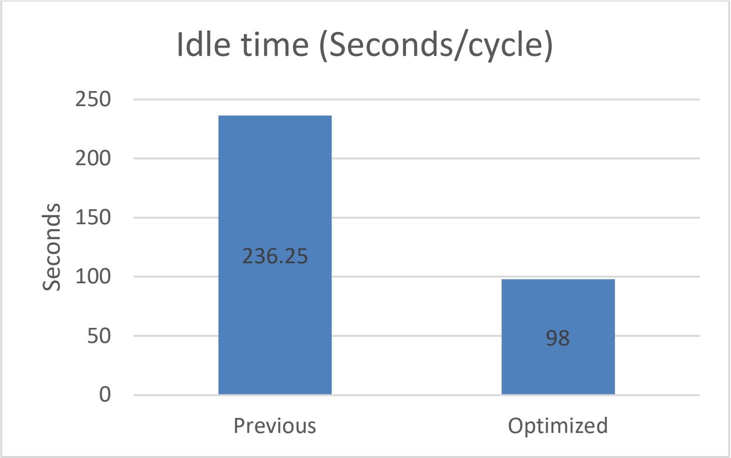

Figure 7 - Graph 4 Previous Vs Optimized Idle Time

- **Efficiency:** Improved from 74.14% to 87.27%, an 18% increase.

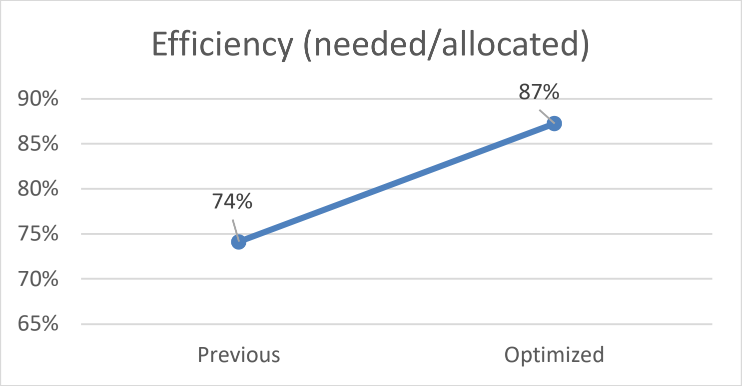

Figure 8 - Graph 5 Previous Vs Optimized Work Station Efficiency

5.2.3. Bottleneck Reduction

The implementation of the line balancing improvements has successfully addressed production bottlenecks and enhanced overall workflow efficiency. By prioritizing tasks according to their Longest Operating Time (LOT) and carefully optimizing task sequences, the production line has experienced significant reductions in bottlenecks. These adjustments have contributed to a more continuous and streamlined production process.

- **Balance Delay:**

Pre-Implementation: The production line initially faced a balance delay of 25.86%. This delay represented the portion of time during which the workflow was disrupted due to inefficient task allocation and idle times at various workstations.

Post-Implementation: After applying the line balancing techniques, the balance delay was reduced to 12.73%. This marks a substantial 51% improvement, indicating that the new task allocations and sequence optimizations have significantly decreased disruptions and idle periods.

INITIAL LINE BALANCE SHEET				
1	Scan MB MES code and Paste it	1	4.95	11.50
	Stick waterproof label	2	2.75	
	Paste screen connector film	3	3.80	
2	Take 50M silicone film and paste it	4	4.95	8.95
	After pasting buckle 16M front camera	5	4.00	
3	Paste 50M conductive	6	2.75	10.25
	Bind 50M rear camera	7	3.50	
	Buckle 50M rear camera	8	4.00	
4	Install the rear camera bracket	9	3.80	9.40
	Paste rear camera conductive	10	2.75	
	Paste rear camera hard foam	11	2.85	
5	Install 8W rear camera	12	6.50	13.00
	Install 3M rear camera	13	6.50	
6	Install distance sensor sleeve	14	5.55	15.75
	Draw motherboard point thermal gel	15	10.20	
7	Three-in-one protective cover installation	16	3.50	7.70
	Remove screen FPC blue film	17	4.20	

8	Attached to the side button FPC	18	7.55	7.55
9	Install the speaker	19	6.00	10.50
	Stick the earpiece conductive cloth	20	4.50	
10	Install F. cam rubber	21	8.00	8.00
11	Install Main Board	22	7.50	11.50
	Inspection of MB	23	4.00	
12	Lock the motherboard screws	24	7.50	13.50
	Paste Front Camera Copper Foil	25	6.00	
13	Assemble the top support bracket components	26	6.70	11.80
	Paste the waterproof Mylar	27	5.10	
14	Paste the graphite sheet of the main board	28	5.10	11.40
	Paste 2 stick screen connector film	29	6.30	
15	Paste waterproof label over small board	30	2.75	10.75
	Fix earphone holder rubber sleeve	31	3.80	
	Fix USB rubber sleeve	32	4.20	
16	Install the small board	33	3.30	9.80
	Bind the small board,	34	3.50	
	Drive the small board screw*1	35	3.00	

17	Connect Coaxial cable	36	7.00	10.30
	Tear off Battery blue film	37	3.30	
18	Align coaxial cable	38	7.50	7.50
19	Install the main FPC	39	9.56	9.56
20	Buckle screen FPC	40	4.20	9.20
	Buckle main FPC	41	5.00	
21	Install the Speaker	42	2.50	8.60
	Install the speaker bracket	43	3.00	
	Lock the speaker bracket screw	44	3.10	
22	Power Consumption Test	45	9.16	9.16
23	Battery binding	46	4.00	10.50
	Battery Assembling	47	6.50	
24	Battery connector buckling	48	2.00	12.80
	Battery & BTB & side button compression	49	10.80	
25	Equip the vibratory motor with conductive cloth	50	5.40	11.00
	Attached the motor to the middle frame	51	5.60	
26	The middle frame is equipped with fingerprint	52	4.50	11.00
	Buckle fingerprint BTB	53	3.00	

	Remove the Camera film	54	3.50	
27	Fix 2M camera rubber sleeve	55	3.50	7.00
	Fix 8W silicone sleeve	56	3.50	
28	1st Appearance	57	13.00	13.00
19	Install the middle frame	58	10.50	10.50
30	Paste NFC Mylar	59	7.72	9.72
	Install whole phone cover	60	2.00	
31	Automatic Screw Locking	61	8.57	8.57
32	Manual Screw lock	62	9.19	9.19
33	Attach screws to prevent heatstroke water Mylar	63	3.30	7.30
	Attach decorative pieces to foam	64	4.00	
34	Attach adhesive for post-photo lens	65	4.33	4.33
35	Attach Camera Deco 1 and lens for decoration	66	13.20	13.20
36	Equipped with rear-camera lenses	67	10.30	10.30
37	Equipped with rear-camera decoration	68	8.18	8.18
38	Pressing of Rear-camera decorations and lenses	69	11.40	11.40
39	PAL and Fragile	70	10.30	10.30
40	2nd Appearance	71	10.41	10.41

41	Configuration	72	11.32	11.32
42	Brightness	73	3.00	13.00
	Far Cam	74	4.50	
	Storage	75	3.50	
	Double Tap	76	2.00	
43	CEC	77	8.00	14.00
	Code Dialing	78	3.00	
	Version Check	79	3.00	
44	Backlight Test	80	2.00	15.50
	Color	81	5.50	
	Key	82	2.50	
	Mic	83	2.50	
	Speaker	84	3.00	
45	Camera	85	8.00	16.00
	PCR	86	4.00	
	Touch	87	4.00	
46	Charging	88	13.20	13.20
47	Earphone	89	4.00	15.00

	FM	90	6.00	
	WIFI	91	2.50	
	Bluetooth	92	2.50	
48	Insert SIM tray	93	4.00	13.50
	SIM Test	94	3.50	
	Storage	95	4.00	
	eject sim tray	96	2.00	
49	OTG	97	5.00	13.00
	PS Calibration	98	4.00	
	LS Calibration	99	4.00	
50	Gravity	100	2.00	14.00
	Drive	101	2.00	
	Distance	102	3.00	
	Light	103	2.00	
	Acceleration	104	2.00	
	Gyro	105	3.00	
51	GPS	106	4.50	15.50
	Dual cam	107	7.50	

	Test Report	108	2.50	
	MMI	109	3.25	
	Remove Silicon Cover	110	2.50	
52	Audio	111	11.28	11.28
53	Ant	112	13.08	13.08
54	Middle frame dispensing	113	10.03	10.03
55	Cover plate manually pressing	114	11.67	11.67
56	The battery cover is pre-pressed on the whole surface	115	10.44	10.44
57	RQC I	116	8.39	8.39
58	Pink Pouches	117	7.61	7.61

Table 12 Initial Balance Sheet Heat Mapping Table

After Optimization: Post-implementation heat maps display a more balanced distribution of workload across workstations. The reduction in color intensity indicates fewer bottlenecks and smoother transitions between tasks, reflecting the improved efficiency of the optimized workflow.

OPTIMIZED LINE BALANCE SHEET				
1	Scan MB MES code and Paste it	1	4.95	13.9
	Take 50M silicone film and paste it	4	4.95	
	After pasting buckle 16M front camera	5	4	

2	Stick waterproof label	2	2.75	13.1
	Paste screen connector film	3	3.8	
	Paste 50M conductive	6	2.75	
	Install the rear camera bracket	9	3.8	
3	Paste rear camera conductive	10	2.75	13.1
	Paste rear camera hard foam	11	2.85	
	Bind 50M rear camera	7	3.5	
	Buckle 50M rear camera	8	4	
S	Install 8W rear camera	12	6.5	13
	Install 3M rear camera	13	6.5	
5	Install distance sensor sleeve	14	5.55	10.2
	Draw motherboard point thermal gel	15	10.2	
6	Three-in-one protective cover installation	16	3.5	13.7
	Remove screen FPC blue film	17	4.2	
	Install the speaker	19	6	
7	Stick the earpiece conductive cloth	20	4.5	12.05
	Attached to the side button FPC	18	7.55	
8	Install F. cam rubber	21	8	8

9	Inspection of MB	23	4	11.5
	Install Main Board	22	7.5	
10	Paste Front Camera Copper Foil	25	6	13.5
	Lock the motherboard screws	24	7.5	
11	Assemble the top support bracket components	26	6.7	11.8
	Paste the waterproof Mylar	27	5.1	
12	Paste the graphite sheet of the main board	28	5.1	11.4
	Paste 2 stick screen connector film	29	6.3	
13	Paste waterproof label over small board	30	2.75	10.75
	Fix earphone holder rubber sleeve	31	3.8	
	Fix USB rubber sleeve	32	4.2	
14	Install the small board	33	3.3	9.8
	Bind the small board,	34	3.5	
	Drive the small board screw*1	35	3	
15	Connect Coaxial cable	36	7	11.2
	Buckle screen FPC	40	4.2	
16	Tear off Battery blue film	37	3.3	10.8
	Align coaxial cable	38	7.5	

17	Install the main FPC	39	9.56	9.56
18	Buckle main FPC	41	5	13.6
	Install the Speaker	42	2.5	
	Install the speaker bracket	43	3	
	Lock the speaker bracket screw	44	3.1	
19	Power Consumption Test	45	9.16	9.16
20	Battery binding	46	4	10.5
	Battery Assembling	47	6.5	
21	Battery connector buckling	48	2	12.8
	Battery & BTB & side button compression	49	10.8	
22	Equip the vibratory motor with conductive cloth	50	5.4	11
	Attached the motor to the middle frame	51	5.6	
23	The middle frame is equipped with fingerprint	52	4.5	11
	Buckle fingerprint BTB	53	3	
	Remove the Camera film	54	3.5	
24	Fix 2M camera rubber sleeve	55	3.5	7
	Fix 8W silicone sleeve	56	3.5	
25	1st Appearance	57	13	13

26	Install the middle frame	58	10.5	10.5
27	Paste NFC Mylar	59	7.72	9.72
	Install whole phone cover	60	2	
28	Automatic Screw Locking	61	8.57	8.57
29	Manual Screw lock	62	9.19	9.19
30	Attach screws to prevent heatstroke water Mylar	63	3.3	11.63
	Attach decorative pieces to foam	64	4	
	Attach adhesive for post-photo lens	65	4.33	
31	Attach Camera Deco 1 and lens for decoration	66	13.2	13.2
32	Equipped with rear-camera lenses	67	10.3	10.3
33	Equipped with rear-camera decoration	68	8.18	8.18
34	Pressing of Rear-camera decorations and lenses	69	11.4	11.4
35	PAL and Fragile	70	10.3	10.3
36	2nd Appearance	71	10.41	10.41
37	Configuration	72	11.32	11.32
38	Brightness	73	3	13
	Far Cam	74	4.5	
	Storage	75	3.5	

	Double Tap	76	2	
39	CEC	77	8	14
	Code Dialing	78	3	
	Version Check	79	3	
40	Charging	88	13.2	13.2
41	Camera	85	8	14
	FM	90	6	
42	Drive	101	2	13
	Light	103	2	
	OTG	97	5	
	PCR	86	4	
43	Touch	87	4	14
	Earphone	89	4	
	Storage	95	4	
	Backlight Test	80	2	
44	PS Calibration	98	4	13.5
	LS Calibration	99	4	
	Key	82	2.5	

	Distance	102	3	
45	Gyro	105	3	13
	Mic	83	2.5	
	Gravity	100	2	
	Speaker	84	3	
	Bluetooth	92	2.5	
46	Insert SIM tray	93	4	11.5
	SIM Test	94	3.5	
	eject sim tray	96	2	
	Acceleration	104	2	
47	Color	81	5.5	12.5
	WIFI	91	2.5	
	GPS	106	4.5	
48	Dual cam	107	7.5	13.25
	Test Report	108	2.5	
	MMI	109	3.25	
49	Remove Silicon Cover	110	2.5	13.78
	Audio	111	11.28	

50	Ant	112	13.08	13.08
51	Middle frame dispensing	113	10.03	10.03
52	Cover plate manually pressing	114	11.67	11.67
53	The battery cover is pre-pressed on the whole surface	115	10.44	10.44
54	RQC I	116	8.39	8.39
55	Pink Pouches	117	7.61	7.61

Table 13 Optimized Balance Sheet Heat Mapping Table

- **Heat Maps:**

Before Optimization: A heat map showing high-intensity areas (red/white) where bottlenecks were prevalent. These areas are marked with longer cycle times and higher idle times.

After Optimization: A comparative heat map indicating a significant reduction in intensity (green/blue) in previously problematic areas. The reduction in color intensity signifies fewer bottlenecks and more efficient task flow.

5.2.4. Resource Utilization

Resource utilization, including labor and equipment, has been optimized due to the line balancing efforts. This has led to more efficient use of resources and better overall management.

- **Man Power:** Reduced from 58 to 55, a 5% decrease.

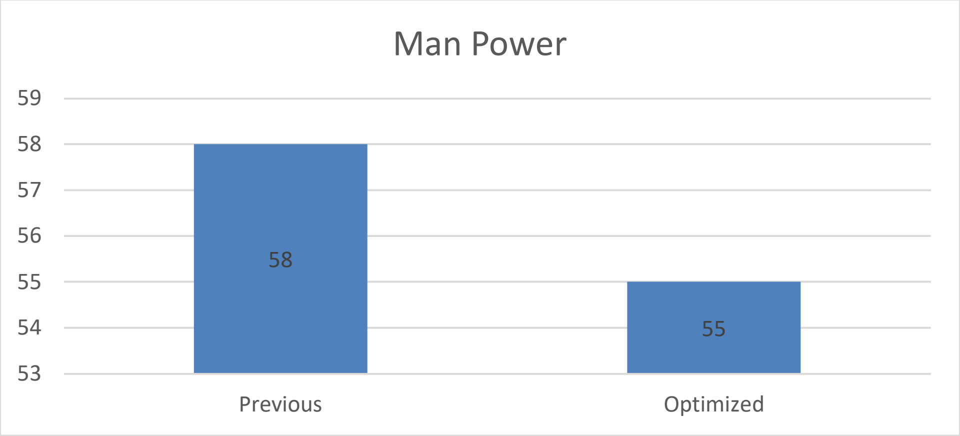

Figure 9 - Graph 6 Previous Vs Optimized Man Power

- **UPPH (Units Per Person Hour):** Increased from 3.94 to 4.68, a 19% improvement.

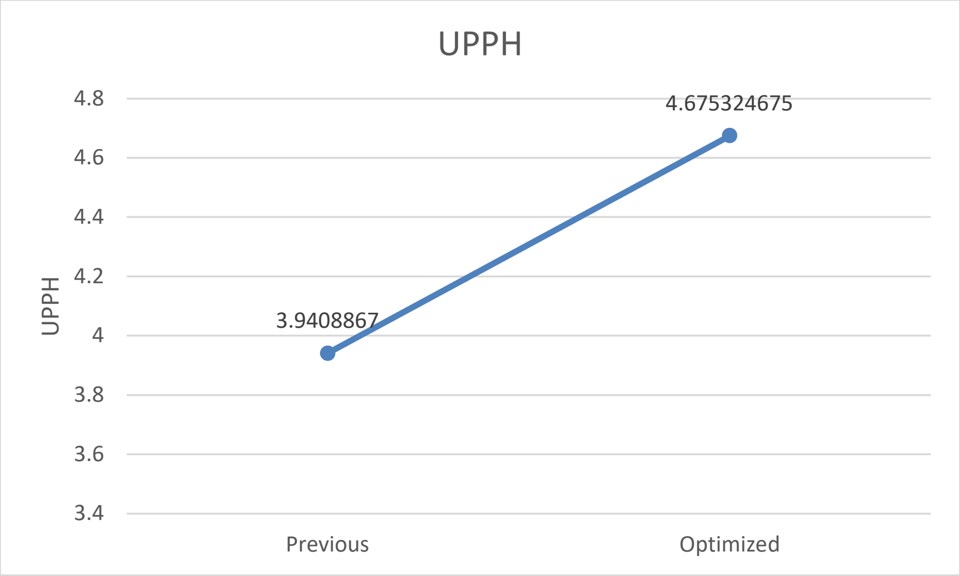

Figure 10 - Graph 7 Previous Vs Optimized UPPH

5.3. Summary Conclusion

The line balancing improvements have led to substantial gains in production efficiency. Key metrics such as cycle time, throughput, and workstation efficiency have all shown significant enhancements. The optimization has effectively reduced idle times and bottlenecks, and improved resource utilization.

Overall Impact:

- **Performance Improvements:** The cycle time has decreased, throughput has increased, and workstation efficiency has been enhanced due to better task allocation.
- **Challenges:** During implementation, process issues were encountered, such as misalignment between theoretical task arrangements and practical execution, leading to defects and process issues. These challenges were addressed by analyzing and readjusting the balance sheet to ensure accuracy and optimal results.

In summary, the line balancing efforts have markedly improved the production line's efficiency and effectiveness. The refined process has optimized workflow and resource utilization, positioning the production process for continued success and future advancements.

SUMMARY OF RESEARCH WORK

The optimization of the production line through the application of the Longest Operating Time (LOT) rule has significantly enhanced operational efficiency and productivity, with notable improvements in cycle time, station efficiency, and overall effectiveness. Key achievements include a reduction in idle time by 59% and an increase in overall efficiency from 74.14% to 87.27%, which collectively led to higher throughput and better resource utilization. Looking ahead, ongoing monitoring, advanced technology integration, and continuous process refinement are crucial for maintaining these gains and driving further improvements, ensuring that the production line remains competitive and responsive to evolving demands.

CHAPTER 6: CONCLUSION AND FUTURE RECOMMENDATION

6.1. Summary

The optimization of the production line through the application of the Longest Operating Time (LOT) rule has led to significant enhancements in operational efficiency and productivity. The key results from the optimization process are as follows:

- **Cycle Time Reduction:** The cycle time was decreased from 15.75 seconds to 14 seconds, reflecting an 11% improvement in processing speed.
- **Station Efficiency:** The number of stations was reduced from 58 to 55, resulting in a 5% increase in workstation efficiency.
- **Time Allocation:** Time allocated per cycle improved from 913.5 seconds to 770 seconds, a 16% enhancement in task execution efficiency.
- **Idle Time Reduction:** Idle time decreased substantially from 236.25 seconds to 98 seconds, marking a 59% reduction and showcasing better utilization of resources.
- **Efficiency Improvement:** Overall efficiency increased from 74.14% to 87.27%, an 18% gain, indicating a more effective use of production time.
- **Capacity Increases:** Both hourly and shift capacities saw a 13% improvement, with units per person hour (UPPH) increasing by 19%.

The optimization process also effectively addressed bottlenecks in the production line. Balance delay was reduced from 25.86% to 12.73%, a 51% improvement, resulting in a smoother and more continuous production flow.

6.2. Conclusion

The implementation of the line balancing techniques, especially the LOT rule, has markedly improved the production line's performance. These enhancements reflect in several key areas:

- **Enhanced Efficiency:** The reduction in cycle time and idle time, along with increased efficiency, indicates a more streamlined production process. The production line now operates with greater speed and effectiveness.
- **Improved Productivity:** The increase in throughput, station efficiency, and capacity per hour and shift demonstrates a notable boost in productivity. The production line is better positioned to meet higher demands and achieve greater output.
- **Effective Bottleneck Management:** The substantial reduction in balance delay highlights the success of the optimization in eliminating production bottlenecks. This has led to a more consistent and efficient workflow.
- **Resource Utilization:** Improved efficiency and reduced idle time signify better use of labor and equipment, contributing to overall cost savings and higher production capability.

In summary, the optimization efforts have successfully transformed the production line, resulting in improved efficiency, productivity, and resource management. The changes have positioned the production line for sustained success and enhanced competitiveness in the industry.

6.3. Future Scope

While the optimization has achieved substantial improvements, there are several areas for further development and continuous enhancement:

1. **Ongoing Monitoring and Adjustment:**

- **Continuous Evaluation:** Regular monitoring and assessment of production metrics are essential to maintain improvements and address emerging issues. An ongoing evaluation system can facilitate timely adjustments and refinements.
- **Feedback Mechanisms:** Establishing robust feedback systems from operators and supervisors can provide insights for continuous improvement and address any operational challenges.

2. **Advanced Technology Integration:**

- **Automation:** Integrating advanced automation technologies, such as robotic systems and automated material handling, could further enhance production efficiency and precision. Automation can reduce manual labor and increase overall accuracy.
- **Real-Time Monitoring:** Implementing real-time monitoring and data analytics can offer immediate insights into production performance, enabling quicker responses and better decision-making.

3. **Process Refinement:**

- **Detailed Analysis:** Conducting in-depth analyses of specific tasks and workstation arrangements can uncover additional opportunities for improvement. A more granular approach may reveal subtle inefficiencies and areas for further optimization.
- **Simulation Modeling:** Utilizing simulation models to test various scenarios can help identify the most effective process improvements and guide informed decision-making.

4. **Employee Training and Involvement:**

- **Training Programs**.
- **Involvement in Improvement.**
- **Scaling Up**
- **Product Line Adaptation**

In conclusion, while the optimization has yielded significant benefits, continuous monitoring, advanced technology integration, process refinement, employee involvement, and scalability considerations will be key to maintaining and further enhancing these improvements. The future scope offers opportunities for growth and innovation, ensuring that the production line remains competitive and efficient in an evolving industrial landscape.

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