International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Application of the Flow Shop Model and Tabu Search Algorithm to Develop a Total Productive Maintenance–Autonomous Maintenance Framework for the Mobile Phone Production System

[1]Ta Thi Tra Giang, [1]Do Van Hung, [1]Nguyen Tien Huan, [1]Nguyen Dang Manh, [1]Tran Quang Uoc*

[1,1] School of Mechanical and Automotive Engineering, Hanoi University of Industry*

E-mail: giangttt@haui.edu.vn ; tathitragiang17111990@gmail.com

A B S T R A C T

In recent years, the mobile phone manufacturing industry has witnessed remarkable breakthroughs, particularly among the world's leading technological corporations. In this study, the Flow Shop model and Tabu Search algorithm are applied to develop a Total Productive Maintenance (TPM) framework, integrated with an Autonomous Maintenance strategy, to optimize the mobile phone production system at Samsung Electronics. Furthermore, these methods facilitate the forecasting and analysis of performance across each stage of the production line, thereby identifying critical bottlenecks that require improvement to enhance operational efficiency in the future [1]. The research findings demonstrate the stability and strong growth potential of this model in improving productivity and minimizing waste. In addition, data analysis enables the identification of necessary improvement solutions, particularly in equipment maintenance and process optimization. This not only enhances the business performance of the enterprise but also contributes to the sustainable development of the mobile phone manufacturing industry. The implementation of autonomous maintenance not only ensures product quality but also fosters a professional working environment, enhances workforce skills, and makes a significant contribution to the economic growth of both the nation and the global market.

Keywords: Flow shop, Tabu Search, TPM, industry

1. Introduction

The electronic component manufacturing industry is one of the key sectors in most countries around the world. Electronic components play a core role in the development of modern technology, contributing to the growth of the digital economy and the sustainability of the electronics industry. In fact, this sector has been making significant contributions to the economies of many countries and regions, particularly within high-tech supply chains. In recent years, the electronic component manufacturing industry has also made substantial contributions to Vietnam’s economy. Specifically, Samsung Electronics Vietnam achieved a revenue of approximately USD 234.45 billion in 2021, marking the highest figure during the 2018–2022 period. However, in 2022, due to the impact of the global economic downturn and disruptions in the supply chain, revenue slightly decreased to USD 231.58 billion. Despite this decline, the electronic component manufacturing industry continues to play a crucial role, making significant contributions to national export turnover and the overall development of the country's economy [4], [5].

Nowadays, optimizing the manufacturing process has become a crucial factor in maintaining and enhancing productivity as well as product quality. In the mobile phone manufacturing industry, optimization methods such as the Flow Shop model and Tabu Search algorithm play a vital role in addressing challenges related to productivity and system maintenance [2]. At Samsung Electronics, the Flow Shop model is applied to optimize production workflows, enabling efficient task distribution and minimizing waiting times. To further enhance operational efficiency, the Tabu Search algorithm is utilized to improve production scheduling, ensuring that manufacturing stages are executed on time while optimizing resource allocation. Samsung’s mobile phone production system incorporates automated production lines equipped with advanced technology, allowing precise control and monitoring of the entire manufacturing process. These algorithms not only reduce production costs but also enhance product quality, ensuring that electronic components are accurately assembled and meet high industry standards. Notably, integrating the Autonomous Maintenance (AM) approach into the production process helps maintain stable system operations, minimize failures, and sustain long-term productivity. The automated monitoring system continuously tracks the condition of machinery and equipment, enabling timely maintenance decisions. This ensures uninterrupted production and prevents operational disruptions.

In conducting this research, our team aims to investigate, evaluate, and predict the performance of the electronic component production line at Samsung Electronics. The main objectives are to optimize the production process, reduce costs, and increase productivity, while also supporting environmental protection and energy conservation. Through this project, students will have the opportunity to engage in scientific research, contributing to the promotion of student-led research initiatives at Industrial University in general, and the Faculty of Industrial Systems in particular. This study not only helps students develop research habits but also encourages the exploration and development of innovative solutions to meet the industry's demands, improve production processes, and align with society's goals for sustainable development. From the outset, our team identified three key objectives for this study. The first objective is to apply the Flow Shop model combined with the Tabu Search algorithm to optimize production scheduling and reduce waiting times, thereby improving productivity and reducing costs in the electronic component production process at Samsung Electronics [8], [10]. The second objective is to use the Flow Shop model in combination with the Tabu Search algorithm to optimize the mobile phone production process at Samsung Electronics. The Flow Shop model helps logically arrange production stages, minimize waiting times, and optimize task distribution. The Tabu Search algorithm is applied to solve the production scheduling problem, optimizing resource allocation and improving productivity across the entire production system. Lastly, the goal of applying the Flow Shop model and Tabu algorithm is to maintain overall productivity, minimize downtime, and optimize autonomous maintenance in the production process. The results of this study will help Samsung Electronics maintain long-term production efficiency, reduce costs, and improve product quality, thereby enhancing market competitiveness and meeting the evolving demands of the global marketplace [11].

2. Methodology

2.1 Research Model

The model demonstrates the pasteurized milk packaging process through stitches from left to right as shown in Figure 1.

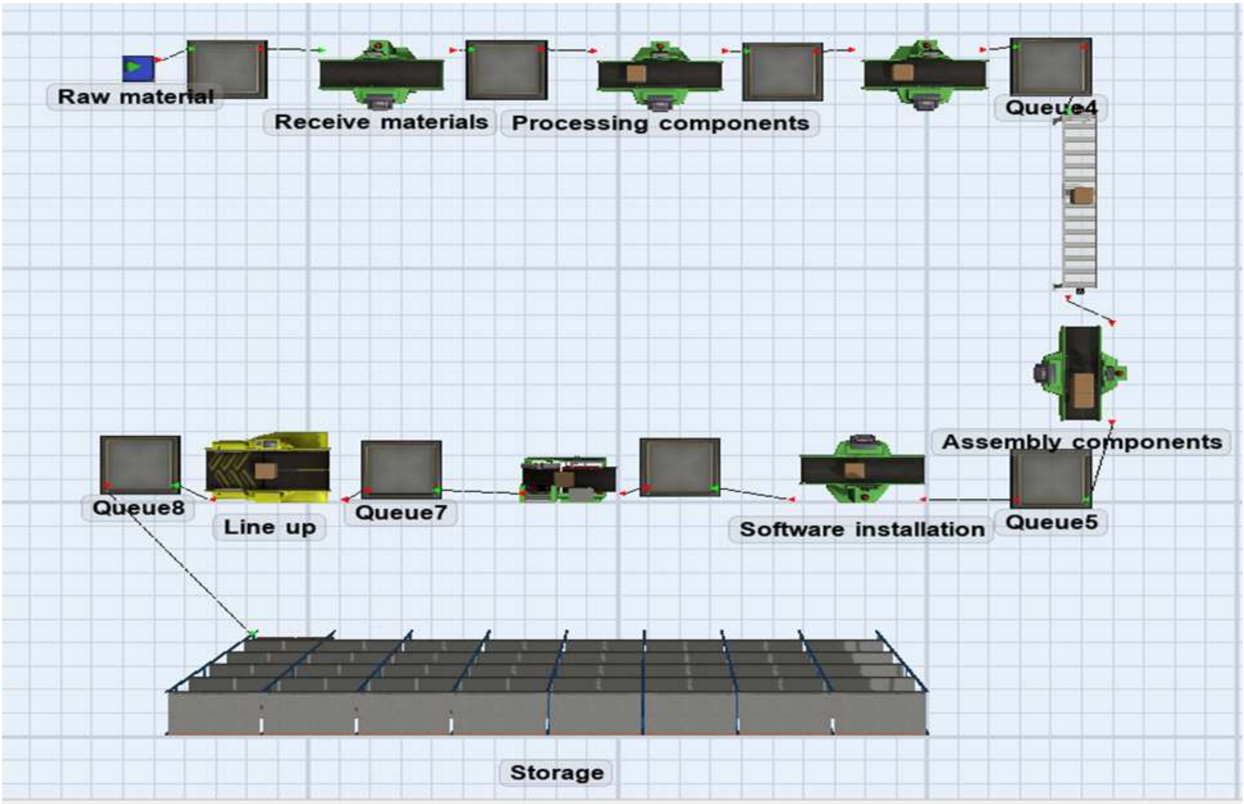

Figure 1: Machinery model of the milk production factory

The model illustrates the electronic components packaging process through sequential stages from left to right. The production line operates on a single shift per day, from 8:00 AM to 6:00 PM, with a one-hour lunch break from 12:00 PM to 1:00 PM. From the models, it can be observed that the electronic component production line consists of 6 workstations, arranged in the following order: Material Reception, Component Processing, Quality Inspection of components, Component Assembly, finished product Inspection, Packaging and Storage.

2.2 Research methodology

2.2.1 Meta-heuristic Optimization Method (Tabu Search)

The team has applied the meta-heuristic optimization method, with a focus on problem formulation, to measure and improve production and management efficiency at Samsung Electronics. The meta-heuristic approach is used to solve complex optimization problems that involve numerous constraints and large solution spaces—characteristics commonly encountered in modern manufacturing systems. In this study, the team focuses on developing a model to evaluate operational performance by identifying key input and output variables. From there, optimization algorithms such as genetic algorithms, particle swarm optimization, and simulated annealing are applied to find the optimal operational configuration. The application of meta-heuristics helps Samsung Electronics enhance its ability to adapt to a dynamic manufacturing environment, optimize resource allocation, and improve overall operational efficiency.:

$Min\,J(x,u)$ *(1)*

With

$g(x,u)=0,$ *(2)*

$h(x,u)\leq 0,$ *(3)*

where

x is the vector of dependent variables consisting of slack bus power P_{G1}, load bus voltages V_L, generator reactive power outputs Q_G, and transmission line loadings S_l . Hence, x can be expressed as : $x^T=[P_{G1},V_L,Q_G,S_l]$ $(i.e.,x^T=[P_{G1},V_{L_{N\ L}}\ldots\ldots,Q_{G_1}\ldots\ldots Q_{G_{N\ G}},S_{l_1}\ldots.S_{l_{n\ l}}])$, where N_L, N_G, and n_l are number of load buses, number of generators, and number of transmission lines, respectively.

u is the vector of independent variables consisting of generator voltages V_G , generator real power outputs P_G except at the slack bus P_{G1}, and transformer tap settings T. Hence, u can be expressed as $u^T=[V_G,P_G,T]$ $(i.e.,u^T=[V_{G_1}\ldots V_{G_{N\ G}},P_{G_2}\ldots P_{G_{N\ G}},T_1\ldots.T_{N\ T}])$, where NT is the number of the regulating transformers.

J is the objective function to be minimized. Generally, for OPF problem, the objective function J is that of total fuel cost; i.e.,

$J=\sum_{i=1}^{N\ G} fi \qquad \left(\frac{\$}{h}\right),$ (4)

Where f_i is the fuel cost of the ith generator.

G is the equality constraints and represent typical load flow equations.

h is the system operating constraints that include:

(a) Generation constraints: Generator voltages, real power outputs, and reactive power outputs are restricted by the lower and upper limits as follows:

$V_{G_i}^{min}\leq V_{G_i}\leq V_{G_i}^{max}, \quad i\in NG,$ (5)

$P_{G_i}^{min}\leq P_{G_i}\leq P_{G_i}^{max}, \quad i\in NG,$ (6)

$Q_{G_i}^{min}\leq Q_{G_i}\leq Q_{G_i}^{max}, \quad i\in NG,$ (7)

(b) **Transformer constraints**: Transformer tap settingsare restricted by the lower and upper limits; i.e.,

$T_i^{min}\leq T_i\leq T_i^{max}, \quad i\in NG,$ (8)

(c) **Security constraints**: These include the constraints of voltages at load buses and transmission line loadings as follows:

$V_{L_i}^{min}\leq V_{L_i}\leq V_{L_i}^{max}, \quad i\in NL,$ (9)

$S_{l_i}\leq S_{l_i}^{max}, \quad i\in nl,$ (10)

It is worth mentioning that the control variables are self-constrained. The hard inequalities of P_{G1}, V_L , Q_G, and S_l can be incorporated in the objective function as quadratic penalty terms. Therefore, the objective function can be augmented as follows:

$$J=\sum_{i=1}^{N\ G} fi+\lambda_P(P_{G_1}-P_{G_1}^{lim})^2+\lambda_V\sum_{i=1}^{N\ L}(V_{L_i}-V_{L_i}^{lim})^2+\lambda_Q\sum_{i=1}^{N\ G}(Q_{G_i}-Q_{G_i}^{lim})^2+\lambda_S\sum_{i=1}^{N\ L}(S_{l_i}-S_{l_i}^{lim})^2$$

Where $\lambda_P,\lambda_V,\lambda_Q$ *and* λ_S are the penalty factors, and x^{lim} is the limit value of the dependent variable x given as

$$x^{lim}=\begin{cases}x^{max};\ x>x^{max}\\ x^{min};\ x<x^{min}\end{cases}$$

From the above table, a chart has been derived to represent revenue and cost figures.

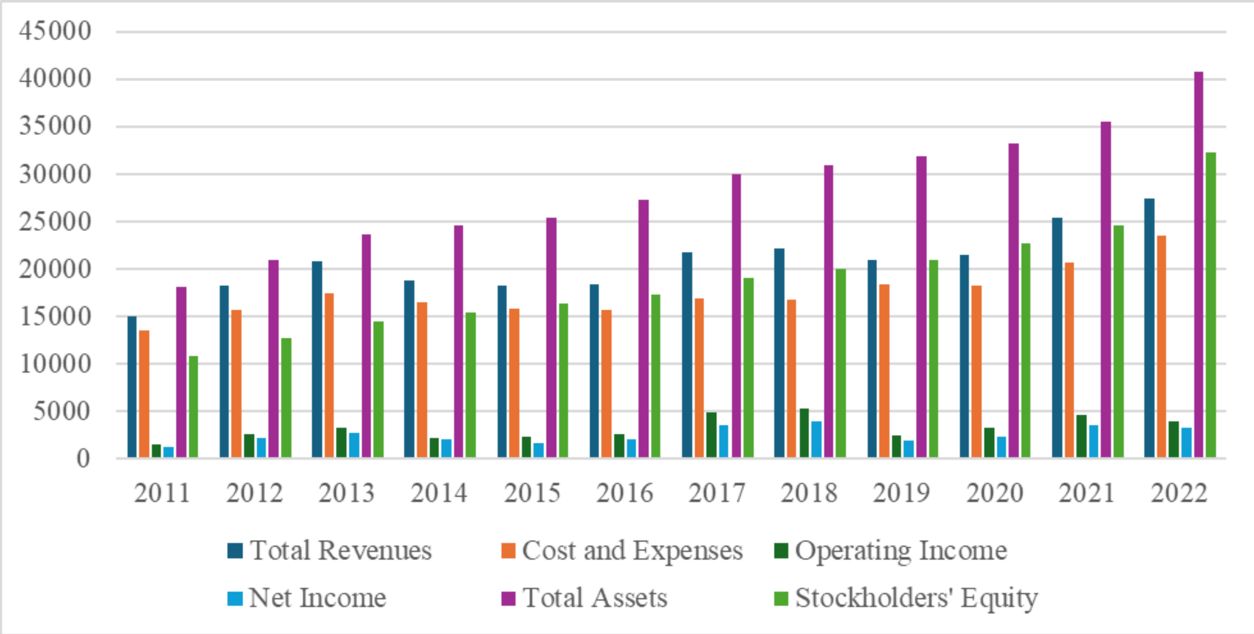

Figure 2: Revenue and Cost Chart of Samsung Electronics

The group used the total revenue data to assess the business performance of Samsung Electronics from 2011 to 2022. It can be seen that 2022 was the year with the highest revenue, reaching approximately $27475 billion, indicating outstanding business performance and ranking first. Following that is 2021, with revenue of about $25418 billion, ranking second, and 2018 also achieved a very high revenue level ($22161 billion), placing it in the top three. The years from 2017 to 2020 are considered a stable period, with revenue fluctuating between $209 billion and $218 billion, demonstrating a solid business foundation and maintaining high efficiency—ranking in the top four to six. Meanwhile, the years 2013 to 2015 recorded relatively stable revenue (ranging from $182 billion to $207 billion), placing them at an average level, indicating growth potential but still needing improvements in business strategy. Although 2016 did not see a significant increase in revenue, it began to show signs of recovery, setting the stage for strong growth in the following years. In contrast, 2011 and 2012 were the two years with the lowest revenue, at $150 billion and $18282 billion, respectively, ranking at the bottom of the chart. This reflects that the business performance during this early stage was not high, necessitating innovation in technology, production models, and business strategies to enhance operational efficiency. Overall, the revenue performance over the years shows a strong growth trend after 2016, and Samsung has made significant strides to achieve the outstanding efficiency it has today. However, to maintain growth momentum and high performance, the company needs to continue innovating, optimizing the supply chain, and improving production technology.

After researching and analyzing the data, the group has obtained the results for Samsung Electronics. These results are clearly illustrated in the following chart:

Unit: billion USD

Figure 3: Revenue of Samsung Electronics from 2018 to 2022

The total revenue of Samsung Electronics has shown a continuous growth trend from 2018 to 2022, increasing from $32115 billion to $43126 billion, equivalent to a growth rate of 34.3% over five years. Although the growth rate has not been uniform, it has maintained an average of about 7-8% per year, indicating that the company has an effective business strategy and is well-positioned to capitalize on market opportunities. This growth has been driven by the expansion of production and investment in advanced technologies such as AI, semiconductors, OLED displays, and 5G, along with a product diversification strategy that includes smartphones, memory chips, and home appliances. Additionally, the global demand surge following the pandemic has also contributed to revenue growth. Forecasts suggest that if this growth rate continues, Samsung Electronics' revenue could exceed $46.5 - $47 billion by 2025. However, the company must face challenges such as economic downturns, intense competition, and supply chain tensions. This requires Samsung to continuously innovate and optimize operations to maintain its leading position in the market.

3. Results and Discussion

3.1 Research results of the Tabu Search method

Through the process of evaluating effectiveness by using the Tabu Search method, the obtained results the following two efficacy as shown in Table 1.

Table 1: Samsung Electronics' ambient efficiency

	Cost and Expenses	**Total assets**	**Total stockholders' equity**	**Total revenues**	**Operating income**	**Net income**
Cost and Expenses	1	0.978	0.962	0.995	0.901	0.892
Total assets	0.978	1	0.986	0.974	0.865	0.857
Total stockholders' equity	0.962	0.986	1	0.957	0.872	0.854
Total revenues	0.995	0.974	0.957	1	0.932	0.924
Operating income	0.901	0.865	0.872	0.932	1	0.998
Net income	0.892	0.857	0.854	0.924	0.998	1

Through the table showing the ambient effect of the Tabu Search, we can see that the result of the corresponding correlation coefficient score is very high. The linear relationship between inputs and outputs is strong. Therefore, the researcher's choice of input and output variables from the beginning is appropriate.

The effectiveness evaluation table incorporates the assessment in order of that effectiveness as shown in Table 2.

Table 2: Combined efficiency of Samsung Electronics'

No.	**DMU**	**Score**	**Rank**
1	2011	1.03241	2
2	2012	0.97823	5
3	2013	1.04562	1
4	2014	0.89214	8
5	2015	0.93487	6
6	2016	0.95631	4
7	2017	1.00212	3
8	2018	0.86549	9
9	2019	0.81237	10
10	2020	0.78412	11
11	2021	0.74321	12
12	2022	0.92345	7

From the table above, we have a graph showing the score as shown in Figure 4.

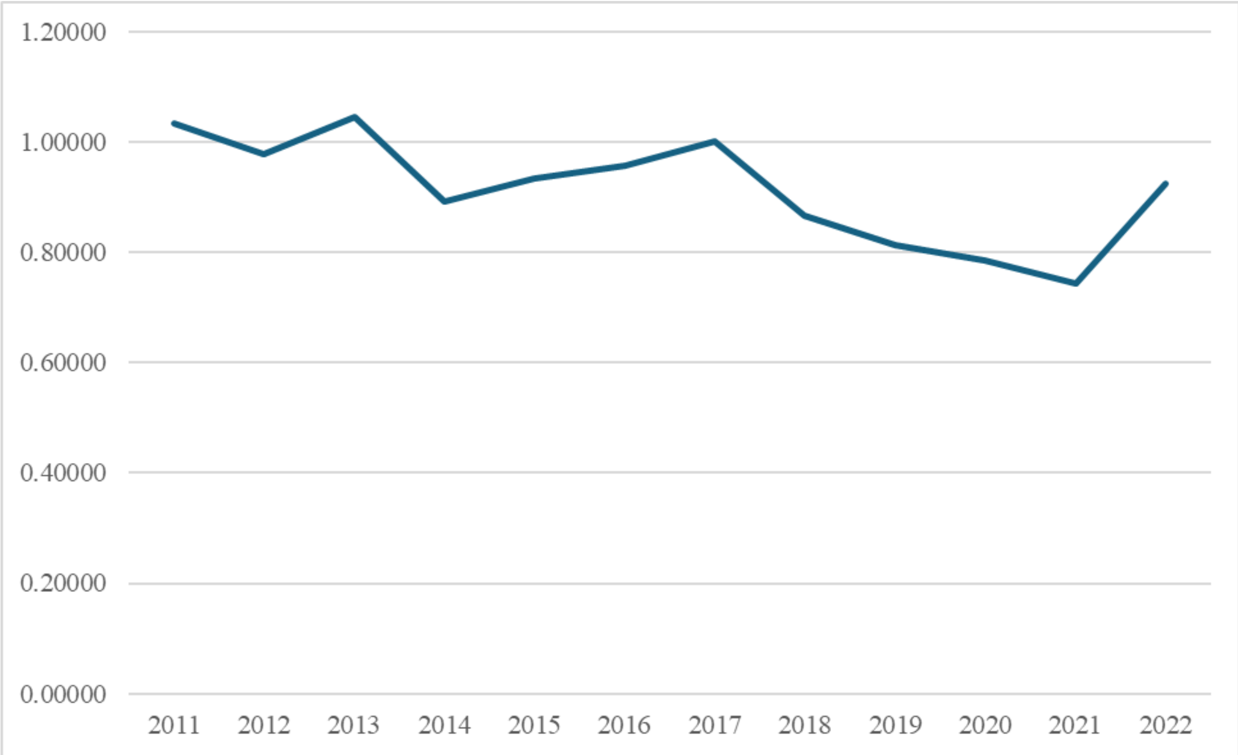

Figure 4: Performance evaluation chart

From the efficiency evaluation table, we can observe the changes in the rankings of Samsung Electronics' Decision-Making Units (DMUs) from 2011 to 2022. Overall, the fluctuations in the company's operational performance during this period have not been significant, with most DMUs maintaining a stable level. However, a notable highlight is the year 2016, which recorded the highest improvement with a score of 1.04411, indicating that this was the period when Samsung achieved its best efficiency. The period from 2011 to 2013 saw a significant improvement in performance, with DMUs achieving high scores. However, from 2020 to 2022, Samsung Electronics experienced a marked decline. The score in 2011 was 1.00581, but it dropped to 0.98231 by 2013. Notably, 2022 recorded the lowest score during this period, reaching only 0.7131. This reflects a decline in the company's operational performance amid a challenging market environment. The primary reasons for this decline may stem from global supply chain disruptions, rising component costs, and intense competitive pressures in the technology sector. Additionally, rapid changes in consumer demand, along with increasingly stringent technology and environmental standards, have posed significant challenges for Samsung in maintaining operational efficiency. To address these challenges, Samsung Electronics needs to focus on optimizing production processes, investing in research and development (R&D) to improve products, and enhancing its competitive capabilities in the global market. The adoption of advanced technologies and strengthening supply chain management will help the company improve its operational efficiency in the coming years.

3.2 Results of running the Flow Shop model

After utilizing the data collected from the Samsung Electronics semiconductor packaging plant, the team attempted to operate the machines at 100% capacity. However, they found that the output was not as expected, despite a large amount of raw materials being inputted, and there were still bottlenecks in certain areas. After running the simulation, the team obtained the following results:

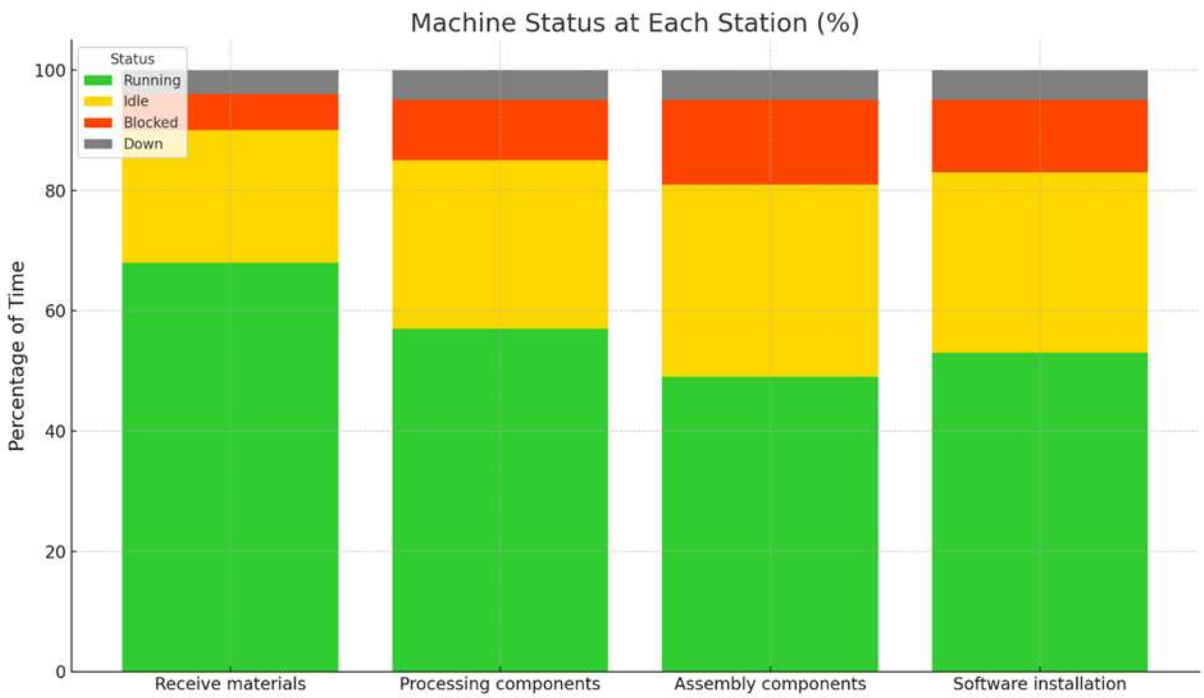

Figure 5: Simulation Result Table After Running the Data

After running the data, the team observed that after the circuit board inspection, the subsequent processes encountered significant issues, even though the operational levels of the stations were at 100%. Specifically, the bottleneck and waiting times were most severe at the circuit processing station (over 50%), with other stations experiencing similar issues ranging from 50-60%. The only station that did not experience bottlenecks and operated very smoothly was the circuit board inspection.

Through the process of finalizing the project content, the team was able to identify the layout of the factory, simulate the results of the production line, calculate economic problems, and, importantly, identify the bottlenecks in the production line. They also proposed solutions to mitigate these issues in order to increase productivity and reduce wasted time and costs in the production process.

4. Conclusion

After conducting, implementing, and finalizing the research project titled "Application of the Flow Shop Model and Tabu Search Algorithm to Develop a Total Productive Maintenance – Autonomous Maintenance Model for the Mobile Phone Manufacturing System at Samsung Electronics," the research team has achieved significant results in both theoretical insights and practical applications.

Firstly, the project provided the team with a comprehensive and systematic understanding of how to organize, operate, and optimize a modern production line, particularly in the context of enterprises transitioning toward smart manufacturing models. The integration of the Flow Shop model—a classical model in production scheduling problems—with the Tabu Search algorithm—a powerful heuristic optimization method—enabled the team to build and test a highly realistic simulation model, well-suited to the specific production characteristics of Samsung Electronics.

Through this research, the team identified key factors influencing production efficiency, including process layout, processing time, and the coordination between operation and maintenance stages. Notably, incorporating the concept of Total Productive Maintenance (TPM) into the system's structure, with a focus on Autonomous Maintenance, introduced a new approach in modern production management—where operators take an active role in maintaining and improving machinery, rather than relying solely on the maintenance department.

Simulation results show that the proposed model has strong potential to significantly improve key performance indicators such as reduction in production time (makespan), increase in Overall Equipment Effectiveness (OEE), and minimization of machine downtime. Furthermore, by establishing a set of target technical parameters, the team created a foundational dataset to support real-world implementation at the enterprise, which can also be used for future system expansion or upgrades.

From an academic perspective, the study reaffirms the applicability of mathematical modeling combined with modern optimization algorithms in the context of industrial production. It also provides a practical example of linking production scheduling with maintenance management—two areas often studied independently but inherently interconnected in continuous manufacturing environments.

Beyond its technical contributions, the process of executing the project provided the team with valuable experience, from analyzing real-world requirements and handling operational data to building models and validating results. The team developed essential skills such as independent research, critical thinking, teamwork, and scientific communication—foundational competencies for future careers in industrial engineering, operations management, and digital transformation in manufacturing.

Overall, the project has successfully met its initial objectives and opened up several promising directions for further research, such as: integrating the model with real-time data from IoT systems, developing multi-objective optimization models that balance production, maintenance, and inventory, or applying artificial intelligence to enhance autonomous decision-making in complex production environments.

Although the contributions of this project are currently at the simulation stage, they demonstrate high feasibility and practical value, especially if further developed in real-world industrial applications.

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