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Analysis and improvement of PCB manufacturing efficiency using discreate-event simulation: An electrical industry use case

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ABSTRACT

The production of Printed Circuit Boards (PCBs) manufacturing is a complex process where companies must constantly balance minimizing costs, ensuring the stringent quality standards demanded by modern electronics, and accelerating production timelines to meet market demands. Discrete Event Simulation (DES) allows manufacturers to create dynamic digital models of their production lines, enabling them to visualize material flows, accurately identify operational bottlenecks, and thoroughly evaluate the potential impact of process changes in a virtual setting. This study improvement project focused on enhancing the lead welding process, likely-through robotic automation-to improve speed and consistency. The comprehensive financial analysis revealed that an initial investment outlay of 1.5 million baht, anticipated over a 5-year operational period, is projected to yield substantial financial returns. Specifically, the project is expected to generate a considerable annual net cash flow, after tax, of 1.98 million baht. Employing a standard corporate discount rate of 10% to appropriately reflect the time value of money and investment risk, the evaluation yielded compelling metrics indicative of strong profitability. The project features a remarkably short discounted payback period of only 10 months, signifying swift recovery of the initial capital invested. Furthermore, it generates a strong positive net present value (NPV) of 1.15 million baht, confirming that the present value of anticipated future earnings significantly outweighs the initial and ongoing costs. The investment's attractiveness is further underscored by an exceptionally high internal rate of return (IRR) of 87% and a robust modified internal rate of return (MIRR) of 61%, which provides a more realistic measure of profitability by accounting for the reinvestment rate of cash flows. This significant outperformance strongly confirms the project's substantial economic value, providing compelling justification for management to confidently proceed with the investment as a strategically sound decision poised to enhance operational efficiency and long-term profitability.

Keywords: Discreate-Event simulation, PCB manufacturing, MIRR, SMT-Line

INTRODUCTION

Discrete Event Simulation (DES) has become a widely recognized industrial analysis tool, particularly valuable in manufacturing for creating detailed production process models. It helps identify weaknesses and improvement opportunities in both resource allocation and operational cost reduction [1, 2]. Modern DES software like FlexSim offers diverse applications spanning from assembly line improvements to transportation management [3-5]. Case studies demonstrate DES's significant role in transforming production systems. Zhang and Liu [3] successfully employed FlexSim to enhance production scheduling, while Jiang and Zhang [4] applied it to flexible assembly lines. Liu and Wang [5] implemented it for transportation planning, showcasing the tool's adaptability [6]. DES applications extend beyond manufacturing, proving useful in healthcare system planning [7] and the automotive industries [6]. Its effectiveness stems from handling system complexity, with Pace [8] detailing crucial simulation accuracy factors. Recent advances in multi-level simulation, particularly Digital Twin applications, have significantly boosted DES's predictive capabilities [9]. Combining DES with automation brings substantial benefits to electronics manufacturing. Lee and Kim [10] found automation increases output while reducing errors, though Garcia et al. [11] caution that thorough financial analysis remains essential. This research focuses on applying DES to enhance PCB manufacturing efficiency by integrating knowledge from flexible production systems [2-6] production scheduling [3] and automation [10, 11] to develop practical industrial solutions. The study results show that investing in automation systems for PCB soldering processes not only leads to increased

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production efficiency and reduced operating costs, but also proves to be highly economically viable based on standard economic investment evaluation criteria, reinforcing the importance of comprehensive financial analysis in business decision-making.

MATERIALS AND METHODS

Manufacturing simulation software that allows manufacturers to simulate production processes and analyze their performance. This program can help manufacturers identify bottlenecks in production processes and find solutions to improve efficiency. The analysis and improvement of printed circuit board (PCB) production efficiency with FlexSim software version 19.1 can be done in the following steps:

1. Collect data about the entire production process, from raw materials to finished products. This data includes information about machinery, equipment, labor, and production steps as shown in Figure 1.

2. Create a model of the production process as illustrated in Figure 3.

3. Analyze the model of the production process and find solutions to improve efficiency as summarized.

4. based on the findings shown in Table 5.

From Figure 1 as shown flowchart within the SMT process (Surface Mount Technology) process is a method of assembling electronic components onto a printed circuit board (PCB). The process begins with the input of the workpiece into the system. The workpiece is then inspected to ensure that it is free of defects. The next step is the soldering process. In this step, the solder paste is applied to the PCB and the components are placed in their correct position. The PCB is then passed through a reflow oven, which melts the solder and bonds the components to the PCB. After the soldering process, the PCB is trimmed to remove any excess solder. The PCB is then cleaned and inspected again. The next step is the assembly process. In this step, the components that were not soldered in the SMT process are added to the PCB. These components include connectors, switches, and other devices. The assembly process is followed by the welding and wiring process. In this step, the components that require welding or wiring are connected to each other. The next step is the transformer installation process. In this step, the transformer is installed on the PCB and the final step the screw and nut installation process. In this step, the screws and nuts are installed to secure the components to the PCB.

From Figure 2. As shown the manual soldering process is a method of assembling electronic components onto a printed circuit board (PCB) by hand. The process is typically used for small-scale production or for components that are too large or complex to be soldered by machine.

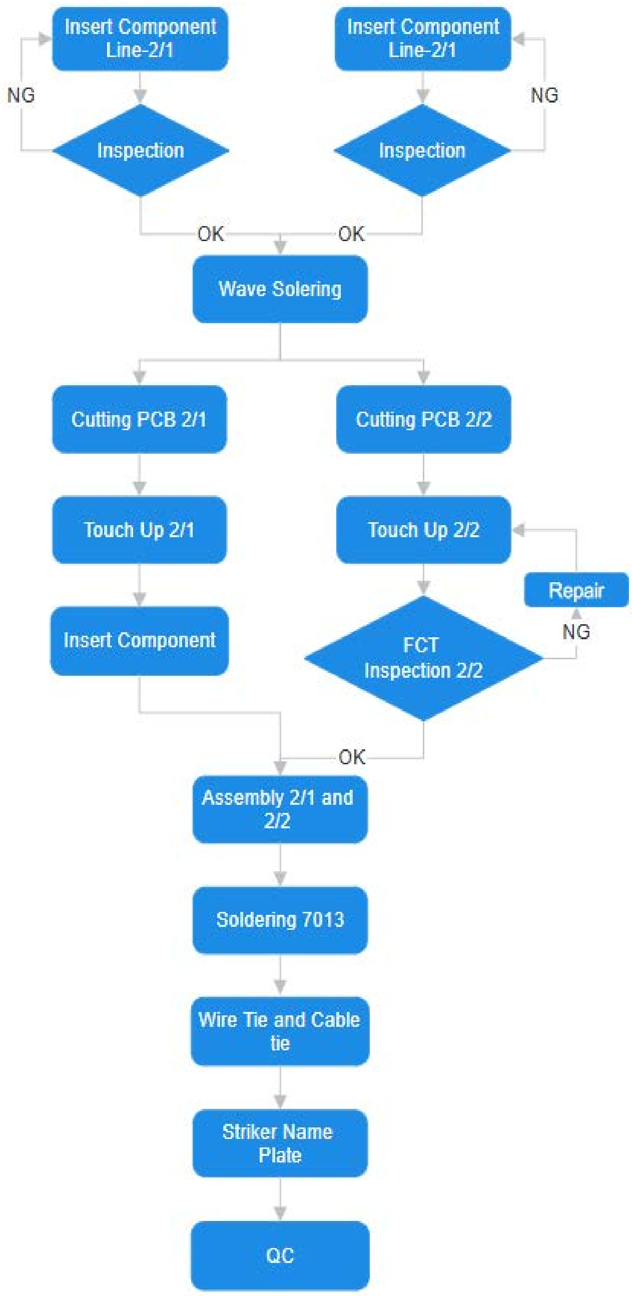

Figure 1 Flowchart within the SMT process.

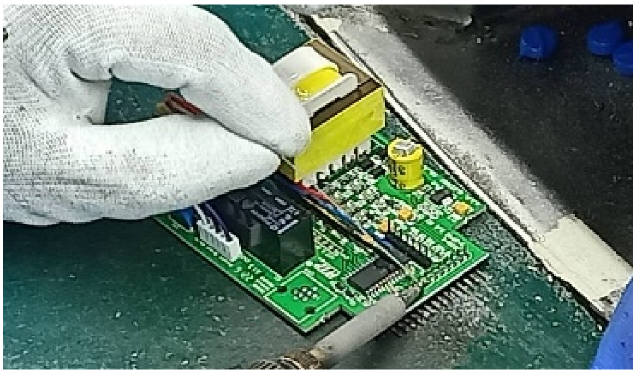

Figure 2 Welding process using manual labors.

This research uses FlexSim version 19.1 manufacturing simulation software, a tool that allows manufacturers to dynamically model manufacturing processes and analyze their performance. This software

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plays an important role in identifying bottlenecks in the manufacturing process and proposing solutions to improve efficiency. It is noted that using FlexSim version 19.1 software, the steps to analyze and improve the efficiency of printed circuit board (PCB) manufacturing are detailed as follows. First, comprehensive data on the entire PCB manufacturing process, from raw material input to finished products, is collected. These data are an important input parameters for the model, including: Machine and equipment data: production capacity, rotational speed, setup time, processing time, breakdown rate, and maintenance time; Labor data: the number of employees working at each station, work capacity, and work schedule; Manufacturing process data: production steps (as shown in Figure 1), cycle time, transportation time, and inter-station storage space; Quality data: defect or defect rate at each step (e.g., 64% quality rate in the manual soldering process as shown in Table 1); Cost data: labor cost, machine cost and the associated investment costs (as shown in Table 3 and Table 5). All of this information is essential to create a model that reflects the reality of the original production system before introducing improvements. Then, a detailed digital model of the PCB manufacturing process was created in the FlexSim environment (as shown in Figure 3). This step is the heart of the process, covering: Layout: Arrange the model of machines, workstations, buffers and conveyor systems to match the actual factory layout; Process Logic: Program or set the logic of each workstation, workpiece movement, process decisions and various working conditions, such as detailed simulation of the SMT process (workpiece feeding, inspection, soldering, cutting, cleaning, assembly, welding, transformer installation, screw and nut installation, labeling and quality control); Parameter Input: Input the data collected in Step 1 into the model so that the model can work under the actual conditions of the original system. Then, when the model is completely created and configured, a simulation is performed to evaluate the performance of the current system and identify areas for improvement. This process includes running a Simulation: Simulate the operation of the production line under the current conditions for a specified period of time to collect performance data. Current Status Assessment: Analysis of the performance data of the manual soldering process before improvement (as shown in Table 1) showed relatively low efficiency, such as output of 471 pieces/day and quality rate of 64%, Solution Determination: Based on the analysis of bottlenecks and desired goals (as shown in Table 2), improvement solutions were developed, such as introducing a robotic automation system for the solder soldering process. Finally, the improvement approach obtained from the analysis was simulated to assess the potential impact before the actual investment. Post-improvement simulation: Create a new simulation model that reflects the proposed change, such as introducing 3 machines and 1 worker in the welding process (as shown in Table 3). Performance comparison: Compare the simulation results between the original system and the improved system by considering key indicators such as reduction in number of workers, cycle time, daily output, and cost (as shown in Table 4 Financial cost analysis: Conduct a comprehensive financial analysis (as shown in Table 5 and Table 6) using criteria such as net present value (NPV), internal rate of return (IRR), adjusted internal rate of return (MIRR), and discounted payback period to confirm the attractiveness of the investment and make a decision recommendation.

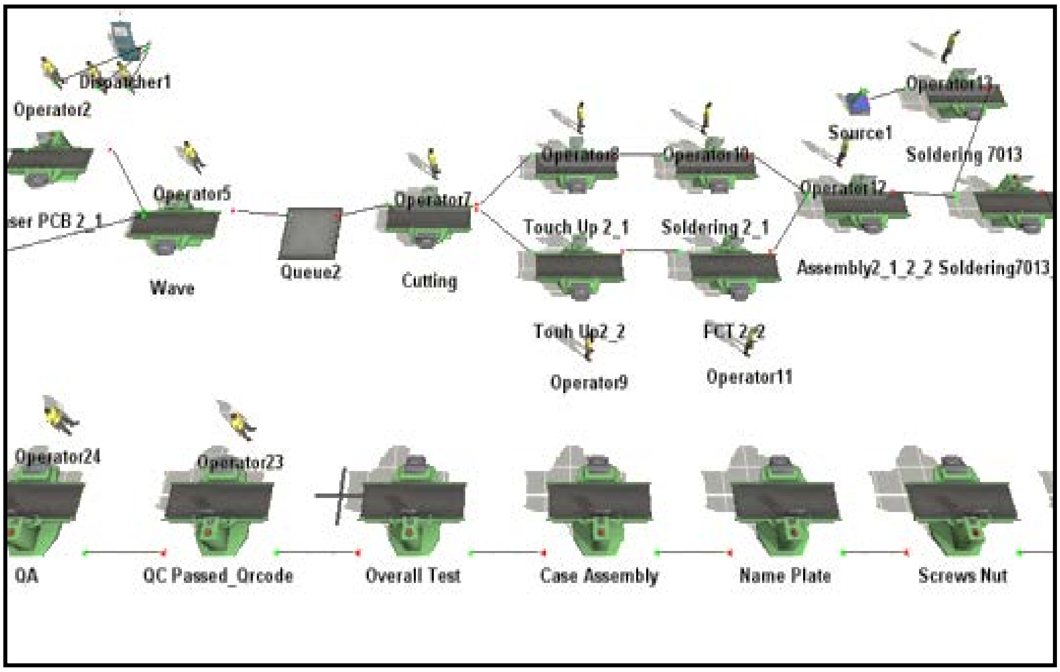

Figure 3 Show an analysis with FlexSim Platform.

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Table 1 Manual soldering process: Before improvement.

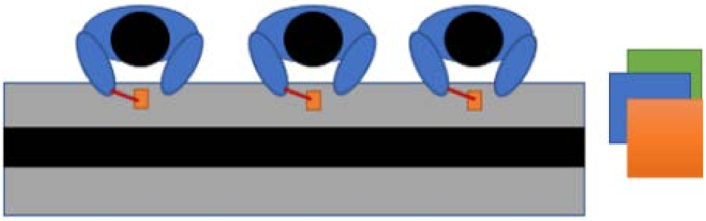
Before: Manual soldering process	
Number of workers	3
OEE	-
Cycle Time (second/pieces)	61.1
Takt Time	-
Capacity / Day (pieces)	741
Productivity (pieces)	471
Quality Rate (%)	64
Lay Out :	
Labor costs (1 employee 15,000 baht/person/month)	30,000-45,000

Table 2 Problems that need to be fixed and improved 5 topics.

Problems that need to be fixed and improved	
Labor	Reduce production costs (reduce workers)
Production capacity	Increase productivity
Quality	-
Technology	Welding robots are used in the production process.
Executive vision	Reduce bottlenecks

Table 3 An automated approach designed for entrepreneurs to make investment decisions.

Directions: Add 3 machines and 1 worker (to control the work)	
Number of workers	1
Number of machines (machine)	3
Cycle time (minute)	12.83
Productivity	797 pieces or 107.56%
Labor costs (15,000 baht/month/person)	15,000 baht/month, 180,000 baht/year
Machinery costs (500,000 baht/machine)	1,500,000 baht/year (excluding maintenance costs for the first year and maintenance cost 10 percent/year: approximately 150,000 baht)
Total net for first 1 year	1,680,000 baht/year
Investment cost (8 baht/circuit board)	6,376 baht/day, 127,520/month or 1,530,240 baht/year
Payback period	About 1 year 2 months

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Table 4 Comparison table before and after improvements.

Comparison table before and after improvements		
	Before	After
Number of workers	3 persons	1 person + 3 machine
Cycle time	95 minutes	91 minutes
Productivity	64 %	107.56 %
Number of pieces/days	471	797
Machinery costs	-	1,500,000 baht
Labor costs	540,000 baht/year	180,000 baht/year
Labor cost + machinery	540,000 baht/year	1,680,000 baht/year
Investment cost	904,320 baht/year	1,530,240 baht/year
Profit/loss per year	364,320 baht/year	-149,760 baht/year
Estimates for the first year		
Payback period	7.17 month	1 year 2 months
There is no burden on machinery costs.		
Labor costs	540,000 baht/year	180,000 baht/year
Machine maintenance costs	-	150,000 baht/year
Labor/machinery costs	540,000 baht/year	330,000 baht/year
Investment cost	904,320 baht/year	1,530,240 baht/year
Profit/loss per year	364,320 baht/year	1,185,240 baht/year
Payback period	7.17 months	2.6 months

Table 5 Numerical data for deciding on investment in production improvement projects.

Project	Numerical data
Investment value	1,500,000 baht
Investment period	5 years
The cost of money or the minimum rate of return desired to be earned.	10%
NPV (Net Present Value)	11,514,525 baht
IRR (Internal Rate of Return)	87%
MIRR (Modify Internal Rate of Return)	61%
DPB (Discount Payback Period)	10 months

Table 6 Payback period calculation table

Payback Period Year	Cash Flow (baht)	Cumulative Cash Flow (baht)
0	(1,500,000)	(1,500,000)
1	1,800,338.20	300,338
2	1,636,671.09	1,937,009
3	1,487,882.81	3,424,892
4	1,352,620.74	4,777,513
5	1,229,655.21	6,007,168

RESULTS AND DISCUSSION

The results of the analysis are as follows: From Table 2 Show the primary challenges to be addressed are increasing production efficiency, reducing costs, and maintaining quality standards. This can be accomplished by integrating technology into the production process and optimizing various operational aspects. Aligning with management's vision, these

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improvements will help alleviate production bottlenecks. From Table 3 Show an automated approach to manufacturing, designed to improve efficiency and reduce costs by introducing 3 machines and 1 worker to oversee the process, offers the following improvements are reduced labor is significantly reduced to just 1, leading to lower labor costs and increased productivity by the cycle time has been reduced to 12.83 minutes per piece, resulting in a productivity increase of 107.56% get output increases to 797 pieces. Whereas the initial investment in machinery is higher, amounting to 1.5 million baht. However, this is offset by reduced labor costs and increased productivity the estimated payback period for the investment is approximately 1 year and 2 months. Table 4, a comparison is shown between the manual soldering process before and after implementing automation. The workforce has been significantly reduced from 3 workers to 1, leading to significant labor cost savings. The cycle time has decreased from 95 minutes to 91 minutes, resulting in a significant productivity boost of 107.56%. The daily output has increased from 471 pieces to 797 pieces. However, the initial investment in machinery has increased the overall cost. While the initial investment is higher, the long-term benefits outweigh the costs. The automated process offers a faster payback period of 1 year and 2 months compared to the previous 7.17 months. From Table 5 This table presents quantitative data used to make investment decisions for production improvement projects. Investment Value: 1, 5 m baht the total amount of money required to invest in this project. Investment Period 5 years. The estimated timeframe for the return on investment. Cost of Money or minimum desired rate of return 10% the minimum expected rate of return from this investment. NPV (Net Present Value) 1.15 m baht. The net present value of the project, indicating its overall profitability. A positive NPV suggests a worthwhile investment. IRR (Internal Rate of Return) 87%. The internal rate of return of the project, which is the rate at which the net present value of the project becomes zero. The higher the IRR, the more attractive the investment. MIRR (Modified Internal Rate of Return) 61% An adjusted version of IRR that considers the reinvestment rate of cash flows. DPB (Discount Payback Period) 10 months. The time it takes for the project to recover its initial investment, considering the time value of money. From Table 6 Payback Period Calculation. This table shows the cash flow generated each year of the investment project and the cumulative cash flow. It is used to calculate the payback period of the project. In year 0, there is an initial investment of 1,500,000 baht, resulting in a negative cumulative cash flow. Subsequently, in years 1, 2, 3, 4, and 5, there is a continuous inflow of cash, causing the cumulative cash flow to gradually increase until it becomes positive. Based on the table, the project can within 1 year, as the cumulative cash flow becomes positive in the first year. This means that the initial investment in year 0 has been recovered.

The automation of the soldering process was a clear success, increasing productivity by 107% (from 471 to 797 pieces/day), reducing production time from 95 to 91 minutes/piece, and reducing the number of workers from 3 to 1. Despite the initial investment of 1.5 million baht, the project was able to achieve payback, within 1 year and 2 months and provided a satisfactory financial return (NPV of 1.15 million baht, IRR 87%), in line with the company's goal of increasing efficiency, reducing costs, and maintaining quality standards. This investment has proven to be worthwhile in the long run and can serve as a model for the development of other production processes.

CONCLUSIONS

The manual soldering process, as outlined in Table 1, was inefficient, labor-intensive, and prone to quality issues. The low productivity and high labor costs were significant concerns. To address these challenges, an automated approach was proposed. As detailed in Table 3, this approach involves introducing three machines and one worker to oversee the process. This automation significantly reduces labor costs, increases productivity, and improves product quality. The initial investment, though substantial, is offset by the long-term benefits. The financial analysis in Table 5 indicates a strong positive NPV, high IRR, and a short payback period, making the investment highly attractive. Table 6 further confirms the rapid payback period, with the initial investment recovered within a year. By implementing this automated solution, the company can enhance its manufacturing process, reduce costs, and improve overall efficiency.

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REFERENCES

1. Wu C, Arbor A. Part 5 human performance mathematical modeling and application in simulation. In: Handbook of Simulation Optimization. Cham: Springer; 2020. p. 483-534.
2. Bortolotti V, Abramo M. Optimization of a flexible assembly line using FlexSim. In: Advances in Production and Management Engineering. Singapore: Springer; 2022. p. 31-40.
3. Zhang Z, Liu Y. Application of FlexSim simulation technology in production scheduling. In: IOP

DOI: 10.60101/jarst.2024.261490

Conference: Materials Science and Engineering. IOP Publishing; 2021. p. 032043.

4. Jiang X, Zhang Y. Research on production scheduling optimization of flexible assembly line based on FlexSim. Journal of Physics: Conference Series. 2022;1968(1):012002.

5. Liu H, Wang J. Application of FlexSim simulation technology in logistics planning. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing; 2023. p. 042001.

6. Rybicka J, Tiwari A, Enticott S. Testing a Flexible Manufacturing System Facility Production Capacity through Discrete Event Simulation: Automotive Case Study. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering. 2016;10(4):668-72.

7. Devapriya P, Stumbled CTB, Bailey MD, Frazier S, Bulger J, Kemberling ST, et al. StratBAM: A Discrete-Event Simulation Model to Support Strategic Hospital Bed Capacity Decisions. J Med Syst. 2015; 39:130.

8. Pace D. Fidelity, Resolution, Accuracy, and Uncertainty. In: Loper M, editor. Modeling and Simulation in the Systems Engineering Life Cycle. Simulation Foundations, Methods and Applications. London: Springer; 2015. p. 29-37.

9. Zhang Z, Guan Z, Gong Y, Luo D, Yue L. Improved multi-fidelity simulation-based optimization: application in a digital twin shop floor. Int J Prod Res. 2022;60(3):1016-35.

10. Lee J, Kim S. Impact of Automation on Productivity and Quality in Electronics Manufacturing. J Manuf Syst. 2020;1-12:54. doi: 10.1016/j.jmsy.2019.12.003.

11. Garcia M. Payback Period and Risk Assessment in Manufacturing Automation. J Clean Prod. 2021;290:125732.

DOI: 10.60101/jarst.2024.261490