Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP07.20260158
Published: March 25, 2026

Optimizing Workforce Shuttle Scheduling System For Multishift Manufacturing Operations Using Integer Linear Programming in a Semi-conductor Company

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Abstract

In manufacturing organizations with various shifts, workers utilize shuttle services to transport employees safely and on time to and from work. In such instances, if shuttle services are planned and organized by human resource staff using calculative tools like spreadsheets, it may lead to effective shutdown and increased fuel costs. The study aimed to integrate an integer linear programming formulation in workforce shuttle service scheduling system at a semiconductor firm with seven shift schedules. To improve data-driven, economical, and sustainable workforce transportation planning systems, this study supports SDG 17 by encouraging cross- functional collaboration and integrating optimization with digital technologies. The integrated system comprises a React frontend layer, a Python FastAPI server layer, and a Supabase PostgreSQL database to support secure and real-time planning and auditing processes. Google Sheets provides the administrative control interface for tariffs and policies. An eight- week evaluation indicated the system to have a high degree of planning accuracy with respect to the operational and fiscal parameters. Total cost accuracy reached 99.61%, and the time spent on weekly planning decreased by 91.25%, as did the shuttle costs by 43.57%. The Wilcoxon signed-rank test showed significant reductions in the time and costs of planning. Results indicate that combining operations-research optimization with modern data infrastructure can significantly improve workforce transportation planning in complex, multi-shift manufacturing environments.

Keywords
Integer linear programming, workforce transportation, shuttle scheduling, operations research, decision support systems.

1. Introduction
Efficient shuttle scheduling is essential in multi-shift manufacturing environments, where reliable employee transport supports smooth shift transitions and uninterrupted operations. In workplaces with day, mid, and night shifts, scheduling becomes more complex due to overlapping work hours, varying labor demands, and time-sensitive transport requirements. Poor shuttle coordination can delay shift start times, disrupt production, and lower worker morale.

Multi-shift production systems maximize equipment use and increase output, but they also create significant logistical challenges. As shift variety increases, transportation planning becomes more critical to ensure the right number of employees arrive on time. Inefficient shuttle scheduling may result in labor shortages, overstaffing, delays, and higher costs. At the beneficiary semi-conductor company, shuttle scheduling is still performed manually. Weekly shift reports from supervisors are consolidated by the Human Resources department, which spends 2–3 hours allocating buses and vans. This process is labor-intensive, error-prone, and causes scheduling issues two to three times per month.

1.1 Objectives

The main objective of this study is to help the company in designing and developing a system that will optimize the shuttle scheduling workforce for multi shift manufacturing operations using linear programming in beneficiary's company Specifically, the study aimed:
1. To assess the existing process of the company related in workforce shuttle scheduling for multi-shift manufacturing operations.
2. To evaluate the causes of inefficient scheduling system for multi-shift manufacturing operations.
3. To formulate Linear Programming Model based on the identified objective functions and constraints to ensure efficient allocation and utilization of transportation resources.
4. To design and develop a system that will improve the company's shuttle scheduling for multi-shift manufacturing operations using linear programming as a decision-support tool.
5. To measure the system's accuracy by comparing the system's planned (system) outputs with the actual outcomes for bus allocation, van allocation, allowance, people/headcount serviced, costs, and demand forecasts.
6.To measure the system's efficiency by comparing the manual (existing) and new (system) process in terms of:
6.1. Process/Planning Time Efficiency
6.2. Cost Efficiency
6.3. Van Allocation
6.4. Bus Allocation
7. To statistically compare the manual (existing) process and new (system) process in terms of:
7.1. Process/Planning Time
7.2. Cost Efficiency
7.3. Van Allocation
7.4. Bus Allocation

2. Literature Review

Production scheduling is a key part of running a factory well. It's the process of planning which machines will do which jobs, based on how the factory is set up and what products need to be made. In job shop systems, this can get tricky because there are many different jobs and only a few machines to do them. The goal is to get everything done in the shortest amount of time. (Phanden et. al. 2025)

To save on operation costs and improve efficiency, companies should design and optimize their shuttle service systems strategically. It requires the handling of multiple constraints, such as fleet size, scheduling complexities, varying demand, and environmental concerns. Optimization techniques are critical in the process since they facilitate the formulation of better and more dependable transportation solutions. (Aydin et.al. 2025)

Wu and Yu (2022) investigated the combination of timetabling, vehicle scheduling, and ride-matching in a flexible, multi-type shuttle system. Their framework considered real-time information, vehicle heterogeneity, and dynamic passenger demand to enhance service quality. The inclusion of speed adjustment, stop-skipping, and holding strategies enabled the system to respond to operational variations.

Peker (2023) used an integer linear programming methodology to give a real-life illustration of an employee shuttle routing problem. The model was designed to reduce total travel time by considering not only shuttle route lengths but also workers' walking times to the stops.

Peker and Eliiyi (2022) made a systematic literature review on routing shuttle bus services in various applications such as for employees, students, patients, and airport travellers. From analysis of research conducted over the last two decades, the review demonstrates an increasing trend in the creation and use of shuttle routing models. The review determines significant modeling approaches and lays open gaps to be explored, highlighting the escalating scholarly and pragmatic interest towards refining shuttle routing models (Peker & Eliiyi, 2022).

Tütüncü et al. (2023) tackled the Personnel Shuttle Routing Problem (PSRP) at Yıldız Technical University using Integer Linear Programming (ILP), a powerful method ideal for addressing constraints and optimizing complex transport logistics. The objective was to minimize total travel distance while ensuring balanced and effective route coverage. The problem was modeled mathematically, implemented in GAMS, and solved in two geographic segments.

Xu and Wang (2022) proposed a two-stage hybrid model combining Integer Programming (IP) and Artificial Bee Colony (ABC) algorithms to schedule call center staff. The first stage addressed hard constraints (e.g., staffing levels, labor laws), while the second refined schedules for preferences and satisfaction. The hybrid model used IP strategically within the ABC algorithm to enhance solution quality. This approach efficiently handled large, complex instances, outperforming traditional methods. The study demonstrated that incorporating IP in metaheuristic frameworks offers robust, flexible, and high-performing solutions to staff scheduling problems in service-driven environments.

Zhang and Xie (2025) presented an extensive review on transportation problems as a certain type of Linear Programming (LP). Within this study, transportation systems were shown to be central to global supply chains and have the potential to affect efficiency and sustainability. Traditional methods such as the northwest corner rule, minimum cost method, Vogel's approximation, and the dual simplex method were assessed for the development of optimal feasible solutions. Their review also illustrates the potential application of transportation models to many contexts, where a strong theoretical foundation holds for shuttle allocation problems. Transportation models are an effective model for the LP and allow organizations to coordinate routes, minimize cost, and allocate resources efficiently even in complex operational procedures.

Barnhart and Fearing (2021) focused on the expense and inefficiencies of air transportation system capacity bottlenecks. They analyzed capacity management challenges in three categories: specification, allocation, and utilization. While the study was on air travel, the implications extended far and wide, most importantly, the necessity for LP and MIP formulations to model limited resource capacity systematically. In shuttle or employee transport systems, neglecting capacity constraints can result in over-assigned vehicles, non-reliable schedules, and sub-optimal resource deployment.

In a university shuttle environment, Mahmoudzadeh and Wang (2020) introduced a clustering-based approach to improve scheduling based on student travel behavior, particularly class start and end times. Their examination of Texas A&M University ridership data indicated expected demand shifts that align with academic schedules. Although their model employed data-driven clustering instead of an LP model, their results unmistakably demonstrate the value of shuttle scheduling in accordance with temporal demand patterns.

Dessouky and Mahtab (2022) solved the Ridesharing Routing Problem (RRP) by formulating flexible pickup and drop-off location selection. Their research presented a Mixed Integer Nonlinear Programming (MINLP) model that combined route generation and passenger service point assignment. For solving large instances, the problem was decomposed into master and subproblems and resolved through branch-and-price heuristics.

Fan et. al (2025) tackled that the important takeaway from their study is that decision variables such as numbers of facilities and quantities allocated must remain non-negative, and usually integer factors can represent reality in operational terms. This reinforces the need to establish and develop non-negativity and integer factors as elements when decomposing the shuttle allocation problems based on linear programming models, to arrive at feasible and practical solutions.

The Why-Why analysis method was used to identify the root causes of organizational problems to make sure that robotics implementation was dealing with latent inefficiencies and not just surface-level issues. The Why- Why analysis method aids an organization in identifying systematic and strategic decision making, which allows organizations to efficiently react to changes in the marketplace and realize the transformative potential of automation. (Bari et. al. 2025)

Zhao et al. (2020) examine 192 actual performance problems and their solutions, identifying common root causes such as improper API usage and noting that small, targeted fixes frequently result in significant improvements. For ES6, front end executing “what-if” scenarios, this confirms the importance of micro-optimizations in loops, collections, and API calls to maintain responsive interactions during peak load, while ensuring maintainability with modular updates consistent with contemporary JS standards.

This research utilized the ISO 25010 product-quality model to evaluate five software tools for climate adaptation planning, considering functionality, reliability, performance efficiency, usability, and compatibility. The authors discovered that ISO 25010 offered a reliable and thorough foundation for comparing varied tools. (Keibach and Shayesteh 2022).
Employing MAD and MAPE effectively represented performance: MAD indicated usual unit volume deficits/surpluses, while MAPE reflected relative fluctuations between locations. Conversely, MSE/RMSE excessively amplified shock-induced outliers and were harder to interpret for staffing/allocation choices. (Napoli et. al. 2023)

Cost efficiency plays a vital role in creating a shuttle allocation system as it guarantees the reduction of operational and user expenses while preserving service quality. The research emphasizes that cost optimization aids in determining the most appropriate vehicle types and service configurations for varying demand levels, enabling decision-makers to allocate resources effectively, minimize unnecessary costs, and attain a balance between affordability, profitability, and passenger contentment. (Estrada et. al. 2020)

Buturac (2021) iterated the methods for assessing and interpreting forecast accuracy, suggesting additional metrics such as MAPE for scale- independent percent error and MAD for deviations in original units. It also tackles sensitivity to outliers and the validity of eliminating special-cause days.

In discussing two-sample location tests, the paper confirms the greater power of the Wilcoxon rank-sum test in non-normal situations and examines a “maximum” composite that selects either t or Wilcoxon. Simulations demonstrate that the composite controls type I error and retains the greater power of the stronger test across distributions. Importantly, the research determines the null limiting distribution of the maximum test and assesses convergence, establishing a strong methodology when normality cannot be assumed. (Kitani and Murukami 2020)

3. Methods

This study used applied research to address the real-world problem of shuttle allocation in a semiconductor company operating multiple shifts. The participants included HR personnel, the HR Head, shuttle service coordinator, Production Supervisors, IT experts, and the researcher. Data were gathered through personal interviews and document analysis of shift records, shuttle schedules, route maps, and transportation costs.

The system was developed using a technology stack composed of React.js for the frontend, Python FastAPI/Flask and PuLP for backend optimization, Supabase and Google Sheets API for data storage and integration, and Minitab for statistical analysis. The procedure began with securing company approval and collecting operational data for two months. These data were then used to build a Linear Programming model for optimizing shuttle allocation.

For analysis, the study used MAPE and MAD to measure forecasting accuracy, an efficiency formula to evaluate improvements in planning time and cost, and the Wilcoxon signed-rank test to compare the manual and optimized systems. System validity was also assessed using ISO 25010.

4. Data Collection

In initial step, the researcher asked to seek accommodation and permission from Fastech Synergy Philippines Inc. by presenting a formal letter and confidentiality agreement. A week later, the management granted the request and explained their concern over the inefficiencies and issues with their existing workforce shuttle scheduling system for multi-shift operations. This resulted in the problem statement and objectives of this research being refined. To solve the research problem, the researcher conducted personal interviews with the HR staff, Production Supervisors, and the shuttle service coordinator to gather comprehensive information regarding employee shift distributions, current shuttle schedules, shuttle capacities, and operational limitations. Documents of the company like employee shift assignments, past shuttle schedules, and costs of transportation are analyzed to establish quantitative data for model development.

Following two months of such data collection activities, the researcher developed a Linear Programming (LP) model from the established constraints and requirements. The LP model was the basis for designing the optimized shuttle scheduling system. Testing of the system is subsequently performed using real company data to determine the performance of the optimized schedules in comparison with the existing manual scheduling practice. Lastly, evaluations are conducted to identify system's accuracy according to how well it predicts and manages resources like vans, buses, allowances, people, and total expenses. Furthermore, the efficiency of time and costs in the process or planning are evaluated by contrasting the current manual process with the newly established system. A comparative analysis subsequently carried out to evaluate the advancements made by the new scheduling method regarding the reduction of planning time, and savings in costs.

5. Results and Discussion

5.1 Existing process of the company related in workforce shuttle scheduling for multi-shift manufacturing operations.

The company operates seven daily shifts and serves about 396 shuttle-dependent workers weekly. HRMD manually collects and verifies Excel templates, consolidates data, and allocates vehicles, a process taking 7–8 hours. Frequent template errors and vehicle mismatches cause delays, underutilization, extra costs, overcrowding, and employee dissatisfaction in weekly shuttle planning (Figure 1).

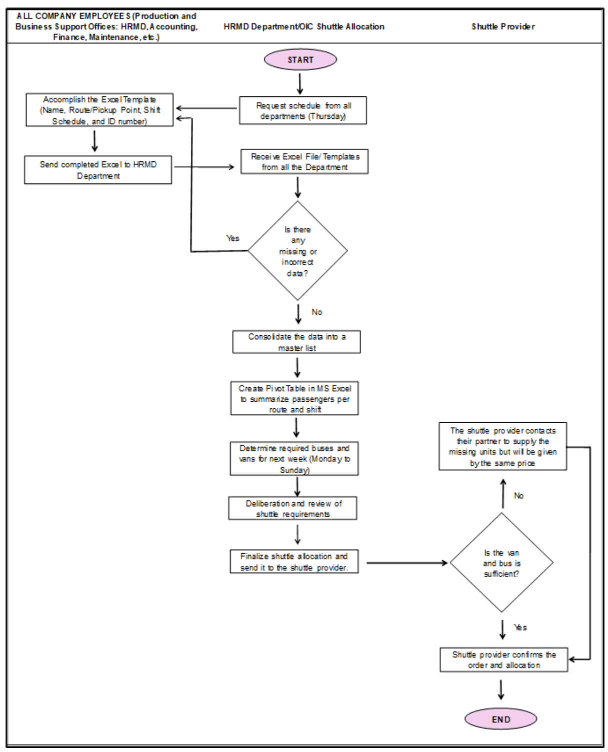

Figure 1. Swimlane Flowchart of the Current Shuttle Allocation Process

5.2 Causes of Inefficient Scheduling System

The shuttle allocation process is mainly constrained by inadequate staff training and the absence of an automated system. HRMD currently performs the entire process manually, from collecting Excel templates and checking missing data to consolidating files, creating pivot tables, and confirming allocations. Because staff lack formal training in shuttle planning and optimization, decisions often rely on subjective judgment, increasing the risk of errors, inefficiencies, and inconsistent vehicle use. The Why-Why analysis showed that repetitive Excel-based work, combined with limited management attention to transportation planning, has prevented the adoption of structured decision-support tools. As a result, shuttle scheduling remains slow, inconsistent, and vulnerable to operational issues, highlighting the need for an optimized and automated scheduling model (Figure 2).

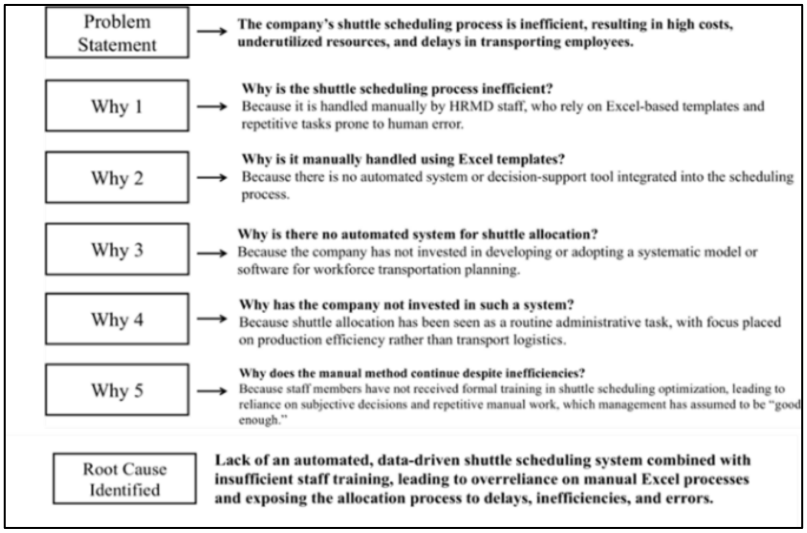

Figure 2. Why-Why Analysis of the Current Situation

5.3 Formulation of Linear Programming Model

The third objective is to develop a mixed-integer linear programming model to optimize shuttle deployment across seven fixed shifts and routes. The model aims to minimize transportation costs, satisfy employee demand, and maximize vehicle utilization while considering capacity, demand, and company policy constraints. Weekly supervisor reports served as the basis for determining shuttle demand for 396 employees. Vans were assigned to low-demand routes, while buses and vans were combined for high-demand areas. The model applied route, capacity, non-negativity, and integer constraints to ensure practical and feasible allocations. Overall, it provides a cost-efficient and reliable decision-support tool for weekly shuttle planning (Figure 3- Figure 4). The design and development of workforce shuttle scheduling system are presented in Figure 5 and Figure 6.

	A Bicutan	B Alabang Express	C Alabang Baybay	D Balibago/ Nestle, Pulo	E Mamatid/San Isidro/Centro mall	F Crossing/Parian/ Paciano Bus Stop	G Canlubang
Bus (x)				2,200 X_D	2,800 X_E	2,800 X_F	
Van (y)	3,000 Y_A	2,000 Y_B	2,000 Y_C	1,200 Y_D	1,500 Y_E	1,500 Y_F	1,500 Y_G
Total Headcount per week	7	7	19	106	137	89	31

Figure 3. Transportation Framework/Model

Decision Variables	x_i = number of buses assigned to route y_i = number of vans assigned to route
General Objective Function	$Min\ P(Cost) = \Sigma\,((x_i)(C_x) + (y_i)(C_y))$ x_i = bus per location y_i = van per location C_x= cost per round trio (bus) C_y= cost per round trio (van)
Actual Objective Function	$\mathrm{Min\ P(Cost)} =$ $3000Y_A+2000Y_B+2000Y_C+2200X_D+1200y_D+2800X_E+1500y_E+2800X_F+1500y_F+1500y_G$ Y_A = Van in location A (Bicutan) Y_B = Van in location B (Alabang Express) Y_C = Van in location C (Alabang Baybay) Y_D = Van in location D (Balibago/Nestle, Pulo) Y_E = Van in location E (Mamatid/San Isidro/Centromall) Y_F = Van in location F (Crossing/Parian/Paciano Bus Stop) Y_G = Van in location G (Canlubang) X_D = Bus in location D (Balibago/Nestle, Pulo) X_E = Bus in location E (Mamatid/San Isidro/Centromall) X_F = Bus in location F (Crossing/Parian/Paciano Bus Stop)
Actual Van Capacity Constraints	$6 \le y_A \le 15$ ----- Location A $6 \le y_B \le 15$ ----- Location B $6 \le y_C \le 15$ ----- Location C $6 \le y_D \le 15$ ----- Location D $6 \le y_E \le 15$ ----- Location E $6 \le y_F \le 15$ ----- Location F $6 \le y_G \le 15$ ----- Location G
Actual Bus Capacity Constraints	$21 \le x_D \le 50$ ----- Location D $21 \le x_E \le 50$ ----- Location E $21 \le x_F \le 50$ ----- Location F
Route Constraints	$y_A \ge 7$ ----- Location A $y_B \ge 7$ ----- Location B $y_C \ge 19$ ----- Location C $x_D + y_D \ge 106$ ----- Location D $x_E + y_E \ge 137$ ----- Location E $x_F + y_F \ge 89$ ----- Location F $y_G \ge 31$ ----- Location G
Non-negativity constraints	$x_i\ , y_i\ \ge 0$ and integers

Figure 4. Mathematical Formulation of the Integer Linear Programming Model for Shuttle Allocation

Figure 5. Logo of FaSTRAS

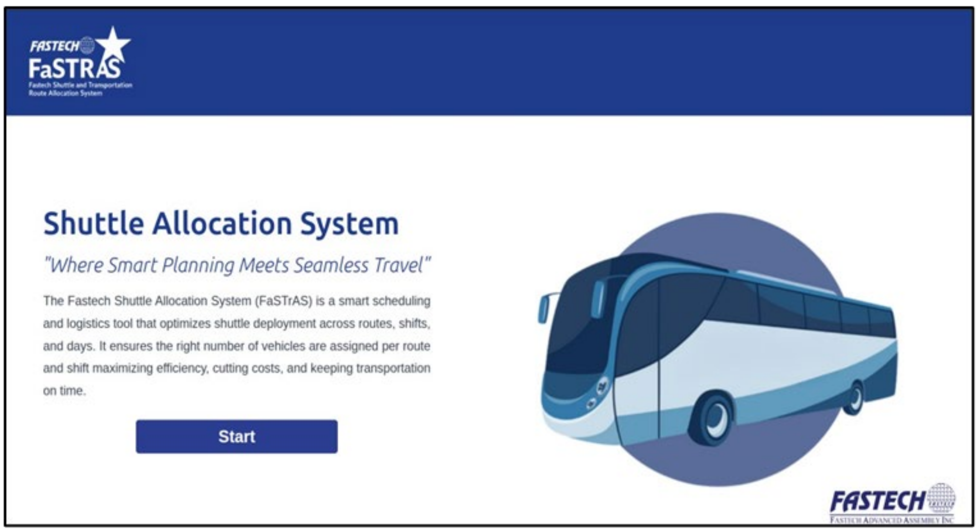

Figure 6. User Interface – Front Screen

The ISO 25010 evaluation of FaSTRAS showed that both end users and IT experts rated the system highly across major software quality dimensions. Among the four HRMD end users, the system was assessed as Very Functional (3.58), Very Efficient (3.63), and Very Usable (3.71). These results indicate that FaSTRAS effectively supports shuttle scheduling tasks, produces generally accurate outputs, performs efficiently under normal workloads, and is easy to learn and operate. End users particularly appreciated its functional appropriateness, learnability, and protection against user errors, showing that the system is practical for daily operations and supports timely decision-making.Similarly, the three IT experts gave FaSTRAS strong ratings in all ISO 25010 categories. The system was evaluated as Very Functional (4.00), Very Efficient (3.89), Very Compatible (4.00), Very Usable (3.72), Very Reliable (3.84), Very Secure (4.00), Very Maintainable (3.87), and Very Portable (3.78). These findings suggest that FaSTRAS is not only effective for end users but also technically sound, secure, adaptable, and suitable for long-term organizational use.

5.4 Comparison of Manual and Developed System

System accuracy measures how closely results match actual values, supporting trust, sound decisions, lower risk, and ISO 25010 suitability. This study used MAD and MAPE because they are practical, easy to explain, and useful for both operations and management. MAD shows errors in actual units, while MAPE expresses them as percentages for fair comparison across routes, shifts, and periods. Findings showed highly accurate performance in bus, van, allowance, employee, and cost allocation, with accuracies above 97%, while forecasting achieved 76.14% or good accuracy. Prior studies also support MAD and MAPE as clear, scalable, and actionable measures for transparent planning and continuous improvement.

5.5 Comparison of manual and developed system in terms of overall system efficiency.

Efficiency is the ability to achieve intended outcomes using the least possible time, effort, and resources. In this study, assessing planning time and cost efficiency between manual and new systems is essential to verify whether the updated shuttle allocation system improves operations. Results showed major gains: planning time dropped by 91.25%, while operating cost decreased by 43.57%. Van allocation was reduced by 60.78% and bus allocation by 29.57%, indicating better vehicle utilization and less unnecessary deployment. These findings confirm that the new system improves productivity, reduces expenses, strengthens service reliability, and supports sustainable, data-driven transportation planning and resource management decisions.

5.6 Statistical Comparison of the Manual (Existing) Process and New (System) Process

The Wilcoxon Signed-Rank Test showed that the new system significantly outperformed the manual process in planning time, cost, van allocation, and bus allocation. For all comparisons, the p-value was 0.0140, which is below the 0.05 significance level, leading to rejection of the null hypothesis. Results confirmed that the new process produced lower median planning time and operating cost, as well as fewer vans and buses required. Cost–benefit analysis further showed strong financial value, with a 1,179.46% ROI and a payback period of only 2.65 months. These findings prove that FaSTRAS delivers statistically significant and practical operational and financial improvements.

6. Conclusion

- The existing shuttle scheduling process of the company was found to be highly manual, time-consuming, and prone to operational errors. With seven daily shifts and around 396 shuttle-dependent employees, HRMD’s reliance on Excel-based consolidation and manual vehicle assignment created delays, mismatches, and inefficient resource utilization. These weaknesses not only increased operational costs but also contributed to overcrowding and employee dissatisfaction, confirming that the current process was no longer suitable for the company’s complex multi-shift transportation requirements.
- The study concluded that the inefficiency of the shuttle scheduling system primarily stemmed from the absence of automation and the limited technical capability of personnel assigned to the task. Since HRMD performed data checking, consolidation, and allocation manually, decisions were often based on subjective judgment rather than structured optimization. The Why-Why analysis further revealed that repetitive spreadsheet work and limited management focus on transportation planning prevented process improvement, making the system inconsistent, slow, and vulnerable to recurring operational issues.
- The formulated mixed-integer linear programming model proved to be an appropriate and effective decision tool for optimizing workforce shuttle allocation. By incorporating demand, route, vehicle capacity, non-negativity, and integer constraints, the model ensured feasible and practical transportation plans across seven shifts and multiple routes. It successfully aligned shuttle deployment with actual workforce requirements, minimized transportation cost, and improved vehicle utilization. Therefore, the model demonstrated strong potential as a systematic and data-driven approach to replacing error-prone manual scheduling practices.
- The development of FaSTRAS successfully translated the optimization model into a functional workforce shuttle scheduling system that is both operationally useful and technically reliable. Based on ISO 25010 evaluation results, the system was rated highly by both end users and IT experts in functionality, efficiency, usability, reliability, security, compatibility, maintainability, and portability. These findings confirm that FaSTRAS is not only acceptable for daily scheduling operations but is also robust enough for long-term organizational use and future system enhancement.
- The developed system demonstrated a high level of accuracy in key operational outputs, particularly in bus allocation, van allocation, allowance, employee servicing, and cost estimation, with results exceeding 97% accuracy. Forecasting performance also achieved good accuracy at 76.14%, indicating that the system can support short-term planning with acceptable reliability. These results suggest that the use of MAD and MAPE effectively validated the system’s predictive and allocation capabilities, thereby

strengthening confidence in the system as a dependable planning and decision-support tool.

- The developed system significantly improved operational efficiency compared with the manual scheduling process. Planning time was reduced by 91.25%, while shuttle operating cost decreased by 43.57%. In addition, van allocation declined by 60.78% and bus allocation by 29.57%, indicating more efficient deployment of transportation resources. These findings confirm that the system not only reduced wasted time and cost but also improved productivity, service reliability, and sustainability, making it a more effective approach for workforce transportation planning in a multi-shift manufacturing environment.
- The statistical analysis confirmed that the developed system significantly outperformed the manual process in all major performance indicators. The Wilcoxon Signed-Rank Test produced a p-value of 0.0140, which is below the 0.05 level of significance, proving that the reductions in planning time, cost, van allocation, and bus allocation were statistically significant. Moreover, the cost–benefit analysis showed a 1,179.46% return on investment and a payback period of only 2.65 months, establishing the system as both operationally effective and financially worthwhile.

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