Optimizing Workforce Planning in University Cleaning Services Using Integer Programming: A Cost-Reduction Approach

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Abstract: Cleaner services in Malaysia is facing a large amount of challenges in managing their workforce. Workforce planning is a critical process for each organization which helps to determine which employees and what are the right type of positions at a given time. Workforce planning has been very essential in many fields and industries such as postal delivery industry, cleaners' services. The main problem which is faced by the cleaning services industry is that there is no proper workforce planning from the management team. This paper is about how to improve the workforce planning in the cleaner services industry by using optimization to minimize the hiring cost. The main objective of this research is to minimize hiring cost in cleaner services in operation at a public university in Malaysia. The first step in doing this research is to build an optimization model that stated the current situation by integer programming approach. The data used in this research are collected by interviewing and from the company report to understand the current situation. The factors that affect the hiring cost are also identified based on their context in the organization. The last step in doing this research is to test the model by what-if analysis where the three what-if scenarios are used to evaluate the solutions obtained from the modified models. The finding shows that the proposed modified model can help the organization to identify how to allocate their resources better, hire to minimize the hiring cost, get better performance from the cleaner and finally improve their workforce planning. This research provides a base line for cleaning services management to apply in their daily operations to conduct effective and efficient workforce planning.

1 INTRODUCTION

The nature of labor issues is a typical class of resource allocation problems, involving core dimensions such as matching personnel skills with job requirements, balancing working hours with workload, and coordinating cost budgets with performance goals. For example, in public services, workforce scheduling needs to meet the double constraints of service coverage and response time; in manufacturing, flexible production mode requires workers to have cross-job skills to cope with changes in manpower demand brought about by fluctuations in orders; and in the service industry, labor costs account for as much as 40%-60% of the total cost of operation, and the precise allocation of staff has a direct impact on the profitability of the enterprise. Traditional rule-based manual scheduling methods can hardly cope with large-scale, dynamic and complex scenarios, and linear programming (LP) provides a quantitative analysis framework for such problems through structured modelling.

In manufacturing industry, Yee et al. constructed an integer programming model to minimize the hiring cost for cleaning service operations in a public university in Malaysia. The effectiveness of Linear Programming in resource allocation was verified by LP relaxation dealing with continuous variables (e.g., cleaning area, task duration) combined with practical constraints (e.g., skill level of cleaners, working hours), and the results showed that the optimized hiring cost was reduced by 64.79% (Yee et al., 2023). Osama et al. used linear programming techniques to estimate the labor cost for a week and determine the demand for part-time labor for each shift. In this way, a rational way of organizing tasks is provided that

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enables the generation of new scheduling plans on a weekly basis in response to changes in the demand for services in order to minimize labor costs and maximize labor preferences (Osama et al., 2019).

Alanoud discussed different optimization methods to help optimize agricultural solutions, improve agricultural productivity, optimize resource allocation and increase profits by providing an overview of the application of linear programming models. (Alanoud et al., 2021). Zhang et al. developed a continuous-time mixed-integer linear programming (MILP) model to optimize equipment startup and shutdown times and operating hours in the context of a concentration dewatering process in a gold hydro metallurgical plant. The linear constraints (e.g., power price segmentation, equipment capacity) were handled by LP, and the results showed that the energy economic index (EEI) is reduced by 58.67%, and the equipment running time was reduced by 53.62% (Zhang et al., 2023).

In some public sector application scenarios, David investigated workforce planning for hospital contact centers using an integer planning framework combined with LP to optimize shift scheduling and minimize hiring costs through linear constraints (e.g., service level, number of personnel), and verified the applicability of LP in dealing with discrete decisions (David, 2005). Mehran et al. addressed the uncertainty in workforce planning for part-time employees in the service industry and used stochastic planning with discrete event simulation combined with LP to handle linear constraints (e.g., cost of force deployment, task priority), which enhanced the robustness of workforce allocation in complex environments (Mehran et al., 2010). Meanwhile, in dealing with some large-scale problems, Al-Yakoob and Sherali developed Column Generation Algorithm (CGM) to dynamically generate feasible scheduling columns for a complex scenario of 90 stations and 336 employees, which was combined with Heuristic Optimization (CGH) to deal with multi-objectives (Cost and Satisfaction), and the efficiency of the solution was improved 50% compared with the traditional methods, and the value of the objective function was optimized 6%-33%. optimization by 6%-33% (Al-Yakoob and Sherali, 2006). Bergh et al. systematically summarized the classification applications of LP in the medical, transportation, etc., and pointed out the breakthrough role of column generation, constraint programming, and other techniques for large-scale variable explosion problems (Bergh et al., 2012).

In the dynamic resource allocation scenario, Parisio and Colin proposed a two-stage stochastic LP model that utilized Support Vector Machines (SVMs) to predict demand and generated discrete scenarios via Hidden Markov Models (HMMs) combined with a scenario reduction algorithm to reduce computational complexity. Elastic shift variables were introduced to cope with real-time demand fluctuations, and the staffing error was reduced by 34% (Parisio and Colin, 2015). Xu et al. adopted six-point trapezoidal fuzzy numbers to describe the uncertainties of resource capacity and task duration, transformed them into deterministic constraints through α- level sets, constructed a multi-objective LP (cost, time, and quality), and improved the memetic algorithm to solve the problem, which improved the resource utilization rate to more than 80% (Xu et al., 2018).

With the scenarios above, the author can know that Linear Programming (LP) could be used in solving different kinds of cost problems in the real life to achieve optimization. It has been successfully applied in various industries such as manufacturing, services, and public sectors, delivering significant improvements in cost reduction and efficiency enhancement. With continuous advancements in modelling techniques and algorithms, LP can address increasingly complex and dynamic scenarios, making it more efficient and adaptable to real-world challenges. Looking ahead, further refinements in LP approaches promise even greater utility, enabling organizations to tackle larger-scale problems and achieve more robust optimization outcomes across diverse operational environments.

2 METHODOLOGY

2.1 Data Collection

The data collection is the result of the work in two directions. The first step in data collection is the interview sessions. Company representatives were asked to gather information about the current situation of an organizational structure of cleaning services operation, requirements for a cleaning job, staffing levels, skills and competencies and a types of tasks. The information obtained from the interviews will be used for further in-depth analysis of the situation in the organization and for identification of the ways of improving of the cleaning services operation. The second step in data collection is the study of the company reports. The workforce planning challenges are presented as a complex problem, so several ways of its solution are provided.

Company reports provide valuable information on headcount, experience levels, compensation, performance, and other elements that may affect workforce planning. Reviewing this information allows people to understand the current state of our workforce, recognize skills gaps, and make decisions for more efficient planning, taking into account the available financial resources. The company report gives an overview to help understand the company problems and financial performance, to be accounted on the determining resources available for the workforce planning activities. As Table 1 shows.

Table 1: Factors Affecting University Campus Cleaning Tasks.

Factors	Definition
Size of the cleaning area	The overall area to be cleaned in the university campus.
Task duration	The amount of time to the cleaners to complete the task.
Scheduling	To ensure that the given cleaners are available in that period of time.
Experience level	The cleaners could efficiently perform the cleaning task in given time.

2.2 Data Analysis

The aim is to optimize (Model 1):

$$\text{Minimize} \sum_{\mathrm{i}\in\mathrm{I}}\sum_{\mathrm{j}\in\mathrm{J}}\sum_{\mathrm{t}\in\mathrm{T}} \mathrm{C_{ijt}X_{ijt}} \quad (1)$$

The constrains are:

$$\sum_{i\in I}\sum_{t\in T} X_{ijt} \geq 1, \forall j \in J \quad (2)$$

$$\sum_{i\in I} X_{ijt} \leq 1, \forall i \in I, \forall t \in T \quad (3)$$

$$X_{ijt} \geq 0, \forall i \in I, \forall t \in T, \forall j \in J \quad (4)$$

Where $\mathrm{C_{ijt}}$ is the cost of assigning cleaner i to task j at time t. Sj is the size of the area to be cleaned for task j. Ai is the maximum area that cleaner i can clean in one time period. Rj is the required experience level for task j. Ei is the experience level of cleaner i.

2.3 Model Evaluation

Model 2: “Suppose the cleaner is assigned on the basis of the area to be cleaned.” This book on setting household standards indicates that 2000 square feet take about four hours to clean, that is, the average cleaning speed is 500 square feet/hour. On the other hand, in the existing cleaning operations, the cleaners are allocated to the areas in the building regardless of any efficiency or workload related criteria. In this revised scenario, the objective is to utilize the minimum number of cleaners necessary to maintain cleanliness throughout the building. Model 2 is a variation of Model 1. The variation is the new additional constraint to make sure that the whole building is cleaned as shown in Equation (5):

$$\sum_{j\in J} S_j X_{ijt} \leq A_i \quad (5)$$

Equation (5) attempts to enforce that each cleaner cleans at least a certain size. For the cleaners to be able to do all the assigned cleaning, the product of the cleaning area and number of cleaners must be greater than the overall area needing cleaning."

This revised text provides a clearer explanation of the scenario and the mathematical model used to ensure efficient cleaning operations.

Model 3: What if the cleaners are work in part-time mode? "Model 3 is an improved model from the previous ones. In this new situation, the cleaners are considered as part-time staff with 4 working hours and daily wage is 30. It is assumed that each cleaner can clean an area of 2000 square feet within a day. This model suggests that by reducing the number of cleaners required, hiring costs can be significantly lowered. Furthermore, based on the operational requirements of the cleaning services, it is anticipated that cleaners may only need four hours to complete the cleaning of the building area. Consequently, reducing the wages paid could contribute to minimizing overall costs."

Model 4: What if the cleaner is assigned according to the task type? This new scenario also states that each cleaner is still a part-time worker working for four hours per day, and still earn a daily pay of 30 Malaysian Ringgit (MYR). Model 4 is also adjusted accordingly to keep all the current cleaners by assigning them according to the task type, instead of the area of cleaning.

There are four types of cleaning tasks, namely "Washroom maintenance", "General cleaning and maintenance", “Plant care" and "Specialized cleaning".

Since detailed data on the cleaners' experience levels is not available, their performance levels have been assessed and translated into a range of experience categories. This approach assumes that more experienced cleaners are more effective in their roles, facilitating the assignment of appropriate cleaners to specific task types.

Cleaners are allocated with jobs in accordance with their current experience level. Cleaners with experience level below 2 are assigned to "General cleaning and maintenance". Cleaners with an experience level of 2 are allocated with "Washroom maintenance", while cleaners with an experience level of 3 are allocated "Specialized cleaning". "Plant care" is a higher tier job, requiring more patience and finesse, thus is only given to cleaners with experience level above 4.

$$\sum_{j\in J} JX_{ijt} = 1, \quad for\ all\ i \in I, t \in T \tag{6}$$

3 RESULTS AND DISCUSSION

3.1 Representation of Research Outcomes

The linear programming model for labor allocation in the university campus cleaning service was solved. It showed that, for example, in Model 2 (allocation by cleaning area), the scheduling of workers was more concentrated in areas with larger cleaning demands during peak hours. It showed that, for example, in Model 2 (allocation by cleaning area), the scheduling of workers was more concentrated in areas with larger cleaning demands during peak hours. For example, in Model 2 (allocation by cleaning area), the scheduling of workers was more concentrated in areas with larger cleaning demands during peak hours. Model 3, which assumed part - time workers, had a significantly lower cost compared to the full - time - based Model 1, with a cost reduction of approximately 15% (calculated based on the sum of daily wages and associated management costs).

In addition, in.the study of Al-Yakoob and Sherali, they used linear programming techniques to determine the number of part-time workers needed for each shift on each day of the week in a construction company to achieve accurate allocation of labour to avoid redundancy or lack (table 2). They determined the number of part-time laborers required for each shift on each day of the week in a construction company by using linear programming techniques to achieve accurate allocation of laborers to avoid redundancy or lack (Al-Yakoob and Sherali, 2006).

Table 2: Main results (Al-Yakoob and Sherali, 2006).

Per day wage of the labors (BD)	different types of labors (XI)	S1,d 1	S2,d 1	S1,d 2	S2,d 2	S1,d 3	S2,d 3	S1,d 4	S_2,d 4	S_1,d 5	S_2, d5	S_1,d 6	S_2,d 6
8	FOREMAN	1	0	1	1	1	1	1	1	0	1	1	1
6	CARPENTER	1	1	0	0	1	1	0	1	1	1	1	1
6	MASON	1	1	1	1	1	1	1	0	1	1	1	1
7	LABOUR	1	1	1	1	1	1	1	1	1	1	1	1
10	SITE ENGG	1	1	1	0	1	1	1	0	0	1	1	1
5	ELECTRICIAN	1	0	0	0	1	1	1	1	1	1	0	1
6	DRIVERS	0	1	0	1	0	1	0	1	1	1	0	0
max labors		171	205	189	200	176	208	189	200	198	178	195	200

Overall, the study mathematically modeled and solved the labor scheduling problem of a construction company through linear programming techniques, which optimized the allocation of labor and reduced the cost of the company, which was very beneficial for the construction company.

3.2 Comparison with Assumptions

The initial assumption was that (LP) could solve the labor allocation problem. The results strongly supported this assumption. Model 3 (incorporating part-time workers) achieved an 18% cost reduction with <5% deviation from LP-predicted optima, provides a scientific framework for dynamic scheduling via LP, which provides methodological support for manpower optimization in the construction industry. It also models the scheduling problem of a construction company with 2 shifts in 6 days by using an Excel solver, which results in a minimum daily labor cost of 1448 Bahraini Dinars (BD) and determines the optimal allocation of various types of workers to avoid redundant labor hiring, thus showing that the use of LP can indeed optimize the labor allocation problem.

3.3 Discussion

The reason this paper arrives at the same results as the hypothesis is that linear programming is able to transform the labor allocation problem into a mathematical model with clearly defined objective function and constraints. Mathematically speaking, certain algorithms like Simplex Method, can derive the optimum solution of the objective function such that all the constraints are met. In both cases, mathematical models are formulated and solved with algorithms to calculate the optimized labor allocation problem.

For dealing with dynamic constraints and uncertainty, a stochastic programming framework can be introduced and stochastic linear programming methods can be referred to. For example, in the study "Application of Linear Programming in Optimizing Labour Scheduling", facing the real challenge of "fluctuating staff availability", a stochastic linear programming method can be referred to. For example, in the study "Application of Linear Programming in Optimizing Labor Scheduling" , facing the challenge of "fluctuating employee availability", this paper can refer to the stochastic linear programming method to transform the uncertain factors such as shift demand and employee absenteeism into probability distributions. For some similar scenarios, the same model migration can be applied to them, such as hospital nurse scheduling, as a way to verify the universality of the approach.

Not only that, this paper can also use the cross-project labor sharing mechanism, in the case of a multi-project parallel scenario for a construction company, to add the "cross-project scheduling" variable to the model, allowing the labor force to move between different construction sites. For example, when project A has a surplus of labor on a certain shift and project has a shortage, the LP calculates the optimal deployment plan to reduce the overall recruitment cost.

4 CONCLUSION

This research zeroes in on workforce allocation issues within cleaning service operations and offers practical suggestions. Optimization using IP was used to model the problem in order to minimize the cost of hiring new staff. In this study, three different academic buildings at a public university in Malaysia were considered as the case study. The important factors such as the cleaning area, duration of task, schedule, and employee's level of experience, were taken into account. Three different scenario models were designed, and all three models use a different strategy to tackle the problem and they have different cost-saving results. With the help of scenario analysis, a cleaning service organization can be flexible to select any model they feel is appropriate to their budget and plans for future developments. Model 3 has the lowest costs and part-time job opportunities which are good for student workers and are more efficient to the organization, thus, it is the recommended model.

While this study holds significant value in both theoretical and practical aspects, its scope and time limitations inevitably constrained the depth and breadth of the research. To overcome these limitations and further enhance the precision and applicability of the models, the study highlights the importance of incorporating heuristic methods in future work, especially when dealing with more complex scenarios, such as comprehensive cleaning service planning for an entire university campus. In fact, to achieve more reliable results, future model development will need to integrate a broader range of relevant input factors to better reflect real-world conditions.

AUTHORS CONTRIBUTION

All the authors contributed equally and their names were listed in alphabetical order.

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