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Optimization of Work Shift Scheduling under Multiple Constraints Using Genetic Algorithm

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Abstract. Work shift scheduling is an essential task in businesses that incorporate both full-time and part-time workers. Work shifts are managed by the store staff and are influenced by various factors. Therefore, as the number of employees and factors to consider increases, the burden of management also grows. Additionally, the importance of each factor varies depending on the preferences of the individual managing the shifts. Thus, this study aimed to automate the process of work shift scheduling optimally based on the importance of each factor. In this paper, a new optimization method is proposed that considers the priority of each factor, represented by an objective function, using a set of Pareto-optimal solutions. Evaluation experiments were conducted using a simulated store, comparing the results of work shifts obtained by the proposed method to those obtained by the existing weighted sum method. The experimental results showed that the proposed method is particularly effective in optimizing multiple objective functions with strong trade-off relations by considering the priority of each objective function.

Keywords: Work Shifts Optimization, Genetic Algorithm, Multi-objective Optimization, Pareto-optimal Solutions

1. Introduction

Work shift is often used in businesses such as restaurants and retail stores that incorporate both full-time and part-time workers. The work shift scheduling is a work format where each employee is assigned specific work hours, and they work in rotation, taking turns. For shift scheduling in Japan, "Preferred shift scheduling" is often used. "Preferred shift scheduling" is a system in which employees request the days of the week and time slots they would like to work each week, based on which work shifts are then assigned. Compared to other shift scheduling methods, "Preferred shift scheduling" offers more flexibility for employees. However, it requires creating completely different work shifts every month. Generally, when assigning work shifts, various factors such as fairness among employees, their capabilities, and working hours are taken into consideration. Here, since the work shifts are created by the staff of the store, the burden of creating work shifts increases as the number of employees and the factors to be considered grow.

To address such issues, numerous studies have been conducted to automate the creation of work shifts by solving mathematical optimization problems [1-3]. When formulating work shift scheduling as a mathematical optimization problem, the factors involved in creating work shifts are expressed as constraint conditions and objective functions. Here, the importance of each factor varies depending on the scheduler. Therefore, optimization that considers the varying importance of each objective function, representing different factors, is required.

In this paper, an optimization method considering the importance of each objective function is proposed, aiming to create work shifts that match the intentions of the work shift creator. Specifically, work shift scheduling using "Preferred shift scheduling" is firstly formulated as a multi-objective optimization problem with multiple objective functions. Next, an optimization method considering the importance of each objective function is proposed.

The rest of this paper is organized as follows: In Section 2, some related works are introduced. Section 3 presents the formulation of work shift optimization and the proposed optimization method, followed by the

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performance evaluation and the results in Section 4. Conclusions are presented in Section 5, and references are provided in Section 6.

2. Related Works

In this section, some related studies are introduced and their drawbacks are discussed. Bechtold et al. [4] minimized personnel costs while satisfying various constraints. However, their model only optimized a single objective of personnel costs without considering any other factors such as fairness and staff quality. Additionally, Trivedi et al. [5] optimized work shifts by solving a mixed integer programming problem, focusing on multiple objectives such as personnel costs and staff quality. Some heuristic and metaheuristic techniques have been reported for efficient optimization. In [6-8], the variable neighborhood search algorithm was introduced for optimization purposes. Additionally, Perlis et al. [9] proposed optimization through genetic algorithm and particle swarm optimization, comparing their effectiveness.

In these studies [5-9], the weighted sum method [10][11] was used to optimize multiple objectives. In the weighted sum method, weights are set according to the importance of each objective function as described in Equation (1), and optimization of multiple objective functions is achieved by minimizing or maximizing the weighted sum.

$$F = \omega_1 \cdot func_1 + \omega_2 \cdot func_2 + \omega_3 \cdot func_3, \omega_i: weight\ of\ func_i \quad (1)$$

The primary focus of these studies [5-9] is on effectively searching a solution with an improved value of the weighted sum. Therefore, they do not place much importance on the difference of significance of each objective function. In the weighted sum method, the importance of each objective function is considered based on weights. However, when the objective functions have complex trade-off relations, it becomes challenging to consider the importance by weights.

3. Proposed Work Shift Optimization Method

There are some factors to consider when creating work shifts, and it is necessary to address cases where the priorities of these factors differ. This study proposes a work shift optimization method using Pareto-optimal solutions, considering the priority of objective functions corresponding to consideration factors.

3.1. Formulation for Mathematical Optimization

Firstly, to formulate the creation of work shifts under the "Preferred shift scheduling" as an optimization problem, the constraint conditions and the objective functions were determined as shown in Table 1 and Table 2, respectively. These were decided based on the factors considered in [12].

Table 1: Constraint conditions

Consideration factors	Constraint conditions
Personnel costs	Only the number of people required is assigned for each time slot.
Preferred work days and times	Days and times they do not wish to work are not assigned.
Expert employee	At least an expert employee is assigned for each time slot.
Employee’s ability	Total score of employees’ skills is above the standard in each time slot.
Working time	Each employee works less than 8 hours per day.

Table 2: Objective functions

Consideration factors	Objective functions
Fairness	func1: Standard deviation of the ratio of each employee’s requested shifts accepted.
Employee’s ability	func2: Average of total skill score of employees for each time slot.
	func3: Standard deviation of total skill score of employees for each time slot.

In "Preferred shift scheduling", the employee’s preferred shifts may not always be granted. To ensure fairness, the func1 is minimized to maintain a constant ratio of accepted requested shifts. In addition, to uphold service quality, each employee’s skill is quantified as a score, and the total score of assigned employees in each time slot is adjusted. Therefore, the func2 is maximized and the func3 is minimized. In this study, work shifts are optimized while setting the priority of these objective functions.

3.2. Pareto-optimal Solutions

In general, work shift optimization involves optimizing multiple objective functions simultaneously. However, in multi-objective optimization, obtaining a unique optimal solution becomes challenging when there are trade-off relations among objective functions. This is because, improving one objective function may lead to the deterioration of other object functions, making it difficult to optimize all objective functions at the same time. To address this, the concept of Pareto-optimal solution [13] is utilized.

A Pareto-optimal solution satisfies two conditions when compared to other solutions:

- It outperforms others in at least one object function.
- It is not worse than others in any objective function.

By identifying solutions that satisfy these conditions, a set of Pareto-optimal solutions can be obtained, representing different trade-offs between objective functions. Selecting a solution from this set allows consideration of the importance of each objective function.

3.3. Optimization Method

When optimizing with a Pareto optimal solution, firstly, the set of Pareto-optimal solutions is obtained from the values of each objective function. Next, since the range of values for each objective function is different, the value of each objective function is normalized with the best value set to 1 and the worst value to 0. In this study, three objective functions are optimized, hence, the set of Pareto-optimal solutions is plotted in three-dimensional space. Figure 1 illustrates an example of the set of Pareto-optimal solutions obtained in this study. Following this, solutions that satisfy Equation (2) are extracted from the obtained set.

$$func_{rank_1} > func_{rank_2} > func_{rank_3},\ func_{rank_i}: objective\ function\ with\ i^{th}\ priority \quad (2)$$

Finally, a solution is selected where the value of the top-priority objective function is the best among the extracted solutions. Thereby, the optimization in this study considers the priority of each objective function.

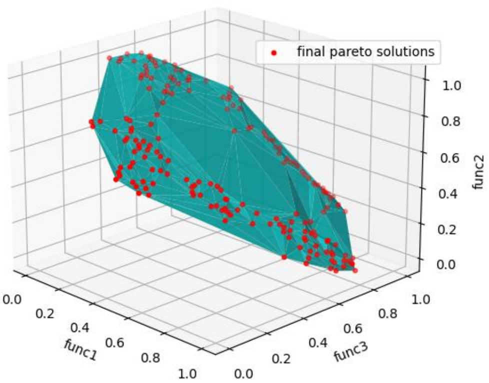


Fig. 1: One of a set of Pareto-optimal solutions obtained

3.4. Implementation

In this study, the proposed optimization method is implemented using genetic algorithm [14], which is an algorithm that seeks an approximate solution to the optimal solution by employing mechanisms of biological evolution such as crossover, mutation, and selection. In work shift optimization, where constraints and objective functions are nonlinear and the number of solution candidates is vast, genetic algorithm proves effective in seeking optimal solutions. In addition, because genetic algorithm operates using a set of solutions, they enable efficient exploration of a range of Pareto-optimal solutions. In this study, Deb's NSGA2 [13] was utilized to seek a set of Pareto-optimal solutions using genetic algorithm.

4. Evaluation Experiment

To verify the effectiveness of the proposed method, an experiment was conducted using a simulated store. The work shifts obtained from the existing method [11] were compared with those from the proposed method.

4.1. Simulation Details

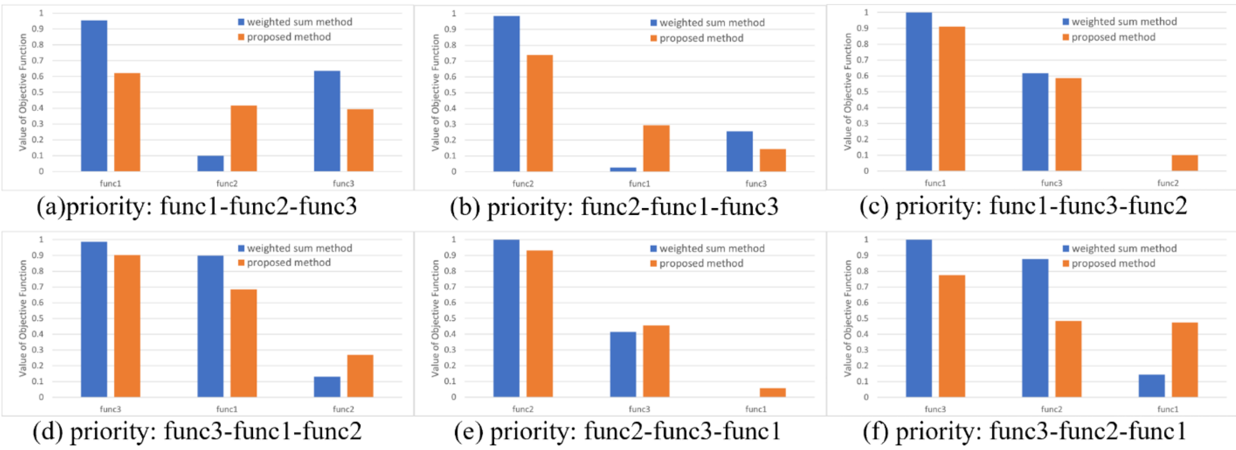
In this study, an experiment was conducted using a simulation based on a virtual store with settings as shown in Table 3. Three patterns, A, B, and C, were prepared by varying the distribution of the number of personnel for each skill level. Pattern A has more skilled workers and fewer beginners, pattern B has the same number of skilled workers and beginners, and pattern C has fewer skilled workers and more beginners. For each pattern, three different preferred shift schedules were generated. The priority of the three objective functions was varied for each preferred shift schedule, and the optimization results were compared with those of the existing method [11].

Table 3: Simulated store settings

Scheduling period	30 days
Time slots	Morning: 8:00-11:00, From morning to afternoon: 11:00-15:00 Evening: 15:00-19:00, Night: 19:00-23:00
Number of employees required for each time slot	4 persons
Number of work shift employees	25 people
Skill level	Expert, Normal, Beginner
Number of employees requesting a shift	Randomly generated so that the number of employees requesting a shift is 1.5 to 2.0 times the number of employees required for each time slot.

4.2. Results

Figure 2 shows the evaluation results obtained by the existing and proposed methods for pattern B (as an example of experimental results), varying the priorities of objective functions. The vertical axis indicates the value of the objective function after normalization. The objective functions with lower priority are shown from left to right. The notations (a) through (f) in Fig. 2 indicate the priority of each objective function.



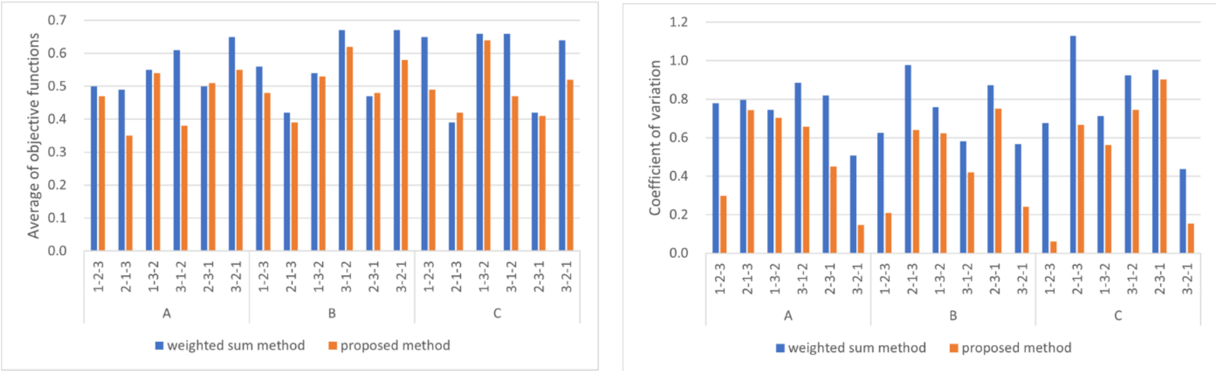
(a)priority: func1-func2-func3 (b) priority: func2-func1-func3 (c) priority: func1-func3-func2

(d) priority: func3-func1-func2 (e) priority: func2-func3-func1 (f) priority: func3-func2-func1

Fig. 2: One of the results for the preferred shift of pattern B

The results shown in Fig. 2 demonstrate that, with the proposed method, the value of the objective function decreased as the priority decreased in all graphs. This indicates that the proposed method could effectively take priorities into consideration. In the existing method, the value of the objective function decreased as the priority decreased in Fig. 2c-f as well. However, the value of the objective function with the second highest priority was the lowest in Fig. 2a and Fig. 2b, indicating that priorities could not be well taken into consideration. Similar results were obtained for patterns A and C, too. Here, Fig. 2a and Fig. 2b show the cases where the func1 and the func2 were set to the first or second priority. The reason why the existing method was not able to reflect those priorities in these cases was that these objective functions had a strong trade-off relation. The existing method simply optimized the value of the weighted sum of multiple objective functions, hence, it was not possible to optimize objective functions that had a trade-off relation. On the other hand, the proposed method selected a solution from the set of Pareto-optimal solutions that reflected the trade-offs of each objective function, resulting in optimizing multiple objective functions that have a trade-off relation.

Figure 3(a) and 3(b) show the average values and coefficients of variation of the objective functions, respectively, as the priorities varied. The descriptions A, B, and C correspond to patterns A, B, and C, respectively, and the three numbers attached to the bar graph represent the types of objective functions (func1, func2, func3), arranged in order of highest priority. As seen from the results, while the average values of the existing method were often higher than the proposed method, the coefficients of variation of the proposed method were always smaller than the existing method. This demonstrates that the proposed method could optimize with less variation in the values of each objective function. This was because the existing method sought the solution that maximized the weighted sum, resulting in a high average value, whereas the proposed method sought a set of Pareto-optimal solutions that took into consideration the balance of the values of each objective function, resulting in a low coefficient of variation.



(a)Average (b) Coefficient of Variation

Fig. 3: Comparison of average value and coefficient of variation of each objective function

5. Conclusion

When creating a work shift, taking into consideration multiple factors is necessary, with the importance of each factor varying depending on the scheduler. Therefore, the purpose of this study was to optimize a work shift while prioritizing the objective function representing each factor. An optimization method was proposed that considers the priorities of each objective function using Pareto-optimal solutions.

In the evaluation experiment, the optimization was performed by assigning different priorities to each objective function for the employees' preferred shifts. The evaluation results revealed that while the existing method failed to consider priorities when optimizing multiple objective functions with strong trade-off relations, the proposed method succeeded. Furthermore, analysis of the average value and coefficient of variation showed that the existing method tended to optimize with a higher average value for each objective function, whereas the proposed method optimized with less variation in each objective function's value. From these results, it can be concluded that the proposed method is effective in optimizing multiple objective functions with strong trade-off relations while minimizing variation by setting priorities for each objective function.

To get closer to the actual shift creation, adding other consideration factors such as relationships between staff and performing optimization taking into consideration the occurrence of vacancies of staff will be studied in the future.

6. References

[1] A.T.Ernst et al., "Staff scheduling and rostering: A review of applications, methods, and models," European Journal of Operational Research, Vol.153, Issue 1, February 2004, pp.3-27.

[2] X Cai, K.N Li, "A genetic algorithm for scheduling staff of mixed skills under multi-criteria," European Journal of Operational Research, Vol.125, Issue 2, September 2000, pp.359-369.

[3] Asgeirsson et al., "Near-optimal MIP solutions for preference-based self-scheduling," Annals of Operations Research, Vol.239, pp.273-293, 2016.

[4] Bechtold et al., "A comparative evaluation of labor tour scheduling methods," Decision Sciences, Vol.22, Issue 4, pp.683-699, 1991, September.

[5] Trivedi et al., “A mixed-integer goal programming model for nursing service budgeting,” Operations Research, Vol.29, Issue 5, pp.829-1034, 1981.

[6] Solos, I.P. et al., “A Generic Tow-Phase Stochastic Variable Neighborhood Approach for Effectively Solving the Nurse Rostering Problem,” Algorithms 2013, Vol. 6, Issue 2, pp.278-308.

[7] Ioannis X. Tassopoulos et al., “A Two-phase adaptive variable neighborhood approach for nurse rostering,” Computers and Operations Research Journal, Vol. 60, August 2015, pp.150-169.

[8] Solos, I.P. et al., “Optimizing Shift Scheduling for Tank Trucks Using an Effective Stochastic Variable Neighborhood Approach,” International Journal of Artificial Intelligence, Vol.14, No. 1, pp.1-26, 2016.

[9] Perlis, V. et al., “Applying Computational Intelligence Approaches to the Staff Scheduling Problem” ECTA 2011, FCTA 2011 – Proceedings of the International Conference on Evolutionary Computation Theory and Applications and International Conference on Fuzzy Computation Theory and Application, pp. 168-173, 24-26 October, 2011.

[10] Burhan Khn et al., “A scalarization-based dominance evolutionary algorithm for many-objective optimization,” Information Sciences, Vol.474, February 2019, pp.236-252.

[11] Nyoman Gunantara et al., “A review of multi-objective optimization: Methods and its applications,” Cogent Engineering, Vol. 5, 2018, Issue 1, pp.1-16.

[12] Takuma Tokunaga et al., “Development of a Staff Scheduling Model for Part-time Employees and a Support System,” Transactions of Information Processing Society of Japan, Vol.8, No.2, July 2015, pp.57-65 (in Japanese).

[13] K. Deb et al., “A fast and elitist multi-objective genetic algorithm: NSGA2,” IEEE Transactions on Evolutionary Computation, Vol.6, No.2, April 2002, pp.182-197.

[14] Melanie Mitchell, “An Introduction to Genetic Algorithms,” MIT Press, 1988.