# Evaluation of Request Order Decision Strategy in the Selection of Substitute Employees for Shift Management Tasks

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***Abstract*—In workplaces with shift-based schedules, managers are burdened with the task of modifying work schedules when absences occur. In this process, known as schedule adjustment due to employee absenteeism, the manager must select a replacement employee (substitute employee) from those originally scheduled to be off-duty on the day of the absence. Within this methodology, a task arises where the manager needs to request substitute attendance from employees who were originally scheduled to be off-duty. The order in which these requests are made to employees is crucial as it directly impacts the burden on both the manager and the employees. This paper proposes a strategy for determining the order of requests based on the probability of acceptance by employees. A simulation model is constructed, and evaluations are conducted for multiple parameter sets. The results of the verification indicate that, when prioritizing the reduction of the understaffed workforce, an ascending request strategy is effective. On the other hand, if prioritizing the manager's burden is essential, a descending request strategy proves to be effective.**

***Index Terms*—nurse scheduling, rescheduling, substitute attendance request.**

## I. Introduction

Shift management, crucial in workplaces with variable work hours like hospitals and call centers, encompasses two main tasks: shift schedule generation and modification. Schedule generation involves creating schedules based on constraints like maximum workdays [1]–[3]. Schedule modification, on the other hand, adjusts schedules due to absences. Conventional methods involve regenerating entire schedules for the absence period, but frequent absences complicate communication and shift changes.

In contrast to this approach, there is a method where an employee (substitute) who does not have a scheduled shift on the day of the absence is selected to fill in for the absentee, and only a partial modification of the schedule is made. In this method, since the majority of the schedule remains unchanged, it does not impose a significant burden on the manager or the employees. However, the manager needs to perform the task of requesting the selected employee to work as a substitute on the day of the absence, and the order in which these requests are made (request sequence) becomes crucial. For instance, if requests are made to specific employees only, those employees may feel a sense of unfairness. On the other hand, an increase in the number of requests from the manager to the employees may result in a significant burden for the manager. Moreover, if a substitute cannot be found, it may disrupt the execution of the task itself.

This paper proposes and evaluates request order determination strategies for selecting substitute employees in shift work systems with frequent absenteeism. Metrics include the insufficient number of employees (task stability), the number of requests (manager's burden), the number of times employees worked as substitutes, and The number of requests received from managers. The insufficient number of employees is prioritized, especially in shift-based workplaces. Using a simulation model, the paper assesses proposed strategies across various parameter sets, identifying characteristics leading to high insufficient employee counts and manager-initiated requests. Differences in these metrics between strategies are discussed.

The simulation model incorporates employees' days off requests and utilizes mathematical optimization solvers to generate shift schedules based on various constraints. Absentees are introduced probabilistically on the generated schedules, and simulations of manager-initiated substitute attendance requests are conducted. The goal is to conclude with effective request order determination strategies depending on the situation, considering the number of times employees acted as substitutes, the number of requests received by employees, and other factors. The paper concludes by summarizing the research in the fifth section.

The structure of this paper is outlined as follows: Section 2 covers related research, section 3 describes the simulation model, section 4 presents the experimental setup, experimental results, and their discussion, and section 5 provides the conclusion of this paper.

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## II. Related Work

### A. Modification of work schedules

This study explores heuristic solutions to dynamic nurse scheduling problems arising from sudden absenteeism, particularly in the context of modifying work schedules in shift management [4]–[7]. Focusing on the hospital setting as a representative workplace with shift work, the research treats the adjustment of schedules due to nurse absenteeism as a dynamic scheduling challenge. The approach involves selecting a substitute attendance and simultaneously revising the entire schedule for the subsequent period to ensure feasibility when a nurse is absent on a given day.

This method addresses the challenge of modifying a nurse's schedule due to another nurse's absenteeism, which can pose a significant burden. The paper discusses a method for selecting substitute attendance by making requests on the day of absenteeism to employees not originally scheduled to work but who can accept substitute attendance without violating schedule constraints established at the time of generation.

### B. Substitute attendance request

In research on the development of methods for requesting substitute attendance, a study has been conducted using real-world data from a call center to examine the relationship between the order of requests to substitute workers and the percentage of understaffed employees [8]. Building upon this study, our paper goes beyond real-world data and conducts simulations of substitute attendance requests for multiple parameter sets. We evaluate the impact of changing the order of requests in these simulations. The various parameter sets verified in our study were constrained to realistic scenarios based on the real-world data from the aforementioned study. Unlikely scenarios, such as all employees being absent on every date within a given period or the existence of employees who always accept substitute attendance requests with a 100% probability, were excluded from the verification.

## III. Simulation model

In the real world, various methods such as phone calls, messaging apps, and oral communication are used for substitute attendance requests. Messaging apps allow simultaneous requests to multiple employees, but there's a concern about securing more substitutes than needed. Oral requests offer prompt responses but can only be made in person, limiting requests to present employees. This paper focuses on "phone calls," a common method for sudden absences, and conducts simulations. We assume one manager making individual substitute attendance requests to each employee.

### A. Generation of a shift schedule through the nurse scheduling problem

With $m$ employees, a duration of $n$ days, and three work shifts each day, the symbols used for the formulation of schedule generation are defined as follows. Additionally, each employee is assumed to submit their preferred days off in advance. We utilized the general-purpose mathematical optimization solver, CPLEX [9].

TABLE I: PARAMETERS AND SYMBOLS OF THIS MODEL

| Parameter | Symbol |
|---|---|
| Number of employees | $X$ |
| Number of dates | $d$ |
| Probability of absence per person | $q$ |
| Maximum request acceptance count per person | $m$ |
| Acceptance probability of low acceptance level | $p_{low}$ |
| Acceptance probability of high acceptance level | $p_{high}$ |
| Number of employees with low acceptance level | $n_{low}$ |
| Number of employees with high acceptance level | $n_{high}$ |

$M = \{1, 2, ..., m\}$ : Set of employees

$N = \{1, 2, ..., n\}$ : Set of dates

$W = \{1, 2, 3\}$ : Set of time slots

$A = \{(i, j), i \in M, j \in N|$

Day off request for employee $i$ on date $j\}$

:Set of employees and day pairs for which day-off requests have been submitted.

$a_k, b_k$ : Minimum (Maximum) number of employees on duty for time slot $k$ per day

$e$ : Maximum number of working days

$r$ : Maximum consecutive working days

$s$ : Maximum consecutive working days for time slot 3.

The decision variable that takes the value 1 when employee i works during time slot $k$ on day $j$, and 0 when not working, is denoted as $x_{i,j,k}$. A feasible work schedule, satisfying all the following constraints for $X = \{x_{i,j,k}, i \in M, j \in N, k \in W\}$ is considered as one work schedule plan.

$$\sum_{k \in W} x_{i,j,k} = 1 \qquad i \in M, j \in N \tag{1}$$

$$a_k \leq \sum_{i \in M} x_{i,j,k} \leq b_k \qquad j \in N, k \in W \tag{2}$$

$$\sum_{j \in N} \sum_{k \in W} x_{i,j,k} \leq e \qquad i \in M \tag{3}$$

$$\sum_{l=0}^{r} \sum_{k \in W} x_{i,j+l,k} \leq r \qquad i \in M, j \in \{1, ..., n-r\} \tag{4}$$

$$\sum_{l=0}^{s} x_{i,j+l,2} \leq s \qquad i \in M, j \in \{1, ..., n-s\} \tag{5}$$

$$x_{i,j,2} + x_{i,j+1,0} \leq 1 \qquad i \in M, j \in \{1, ..., n-1\} \tag{6}$$

$$x_{i,j,k} = 0 \qquad i \in M, j \in N, k \in W, (i,j) \in A \tag{7}$$

### B. Occurrence of absence and substitute attendance request

In the schedule generated in the previous section, absence occurrences and the process of securing substitute workers are performed day by day from the first day to the last day. In this model, to represent the sudden absence of employees, it is assumed that employee absence notifications are received on the day before the absence.

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TABLE II: VERIFIED PARAMETER SETS

| | $q$ | $m$ | $m$:increment | $p_{low}$ | $p_{high}$ | $p_{high}$:increment | $n_{low}$ | $n_{high}$ |
|---|---|---|---|---|---|---|---|---|
| $q = 0.05$ | 0.05 | $2 \leq m \leq 3$ | 1 | 0.05 | $0.40 \leq p_{high} \leq 0.50$ | 0.10 | 40 | 10 |
| | 0.05 | $2 \leq m \leq 6$ | 1 | 0.05 | $0.50 \leq p_{high} \leq 0.90$ | 0.10 | 45 | 5 |
| $q = 0.10$ | 0.10 | $2 \leq m \leq 4$ | 1 | 0.05 | $0.50 \leq p_{high} \leq 0.70$ | 0.20 | 35 | 15 |
| | 0.10 | $2 \leq m \leq 6$ | 1 | 0.05 | $0.70 \leq p_{high} \leq 0.90$ | 0.20 | 40 | 10 |
| | 0.10 | $2 \leq m \leq 6$ | 1 | 0.10 | $0.50 \leq p_{high} \leq 0.90$ | 0.20 | 40 | 10 |
| | 0.10 | $2 \leq m \leq 4$ | 1 | 0.10 | 0.50 | 0 | 35 | 15 |
| | 0.10 | $2 \leq m \leq 13$ | 1 | 0.15 | $0.50 \leq p_{high} \leq 0.90$ | 0.20 | 45 | 5 |
| | 0.10 | $2 \leq m \leq 6$ | 1 | 0.15 | 0.50 | 0 | 40 | 10 |
| | 0.10 | $2 \leq m \leq 4$ | 1 | 0.15 | 0.50 | 0 | 35 | 15 |
| | 0.10 | $2 \leq m \leq 13$ | 1 | 0.20 | $0.50 \leq p_{high} \leq 0.70$ | 0.20 | 45 | 5 |
| $q = 0.15$ | 0.15 | $2 \leq m \leq 6$ | 1 | 0.05 | 0.90 | 0 | 35 | 15 |
| | 0.15 | $2 \leq m \leq 6$ | 1 | 0.10 | $0.70 \leq p_{high} \leq 0.90$ | 0.20 | 35 | 15 |
| | 0.15 | $2 \leq m \leq 10$ | 1 | 0.10 | 0.90 | 0 | 40 | 10 |
| | 0.15 | $2 \leq m \leq 6$ | 1 | 0.15 | $0.70 \leq p_{high} \leq 0.90$ | 0.20 | 35 | 15 |
| | 0.15 | $2 \leq m \leq 10$ | 1 | 0.15 | $0.70 \leq p_{high} \leq 0.90$ | 0.20 | 40 | 10 |
| | 0.15 | $2 \leq m \leq 6$ | 1 | 0.20 | $0.50 \leq p_{high} \leq 0.90$ | 0.20 | 35 | 15 |
| | 0.15 | $2 \leq m \leq 10$ | 1 | 0.20 | $0.50 \leq p_{high} \leq 0.90$ | 0.20 | 40 | 10 |
| | 0.15 | $2 \leq m \leq 20$ | 1 | 0.20 | 0.90 | 0 | 45 | 5 |
| | 0.15 | $2 \leq m \leq 10$ | 1 | 0.25 | $0.50 \leq p_{high} \leq 0.90$ | 0.20 | 40 | 10 |
| | 0.15 | $2 \leq m \leq 20$ | 1 | 0.25 | $0.50 \leq p_{high} \leq 0.90$ | 0.20 | 45 | 5 |

For each $i$,$k$ pair that satisfies $x_{i,j,k} = 1$ for date $j$ and $k \in W$, the absence is triggered by updating $x_{i,j,k} = 0$ with a probability $p$.Substitute attendance candidates for time slot $k$ on date $j$ are employees who satisfy $\sum_{k \in W} x_{i,j,k} = 0$ and do not violate the constraints in Equations (3), (4), (5), and (6) in Section III-A.

Substitute attendance candidates are determined in the order of requests, and requests are made one by one in order. The employee who receives the request responds with acceptance or rejection based on a probability, which is referred to as the acceptance probability. When the request is accepted, we update it to $x_{i,j,k} = 1$. The request is concluded when the number of acceptances matches the number of occurred absences. Otherwise, we proceed to the next substitute worker for the request. When responses are obtained from all substitute employees, if the number of acceptances does not match the number of occurred absences, we consider the substitute for date $j$ as insufficient. This process is repeated sequentially for all dates.

To prevent a specific employee from disproportionately accepting substitute attendance requests, set an upper limit on the number of times each employee can accept requests within a given period. This upper limit is referred to as the maximum acceptance count.

In this simulation model, we categorize employees into two groups based on their acceptance probabilities: those with a low acceptance probability, denoted as $p_{low}$, and those with a high acceptance probability, denoted as $p_{high}$. Additionally, we represent the assigned number of employees in each category as $n_{low}$ and $n_{high}$, respectively.

### C. Request Order Decision Strategy

The evaluation in this paper focuses on acceptance probability-based request order determination strategies: descending request strategy, ascending request strategy, and random reuest strategy. The descending request strategy prioritizes employees with high acceptance probabilities, likely reducing the overall number of requests. Conversely, the ascending request strategy targets employees with low acceptance probabilities first, potentially conserving high-acceptance employees with high acceptance levels for later requests and mitigating the insufficient number of employees. The random request strategy serves as an intermediate approach between descending and ascending request strategies.

## IV. Experiment

### A. Experimental purpose

Simulations will evaluate three request order determination strategies, as discussed in Section III-C, using multiple parameter sets presented in Table I. Notably, $X = n_{low} + n_{high}$, and $p_{low} < p_{high}$. For this study, the number of employees is set to $X = 50$, and the observation period is $d = 28$ days (4 weeks). The goal is to analyze, for each parameter set, the occurrence and extent of the anticipated properties of the strategies outlined in Section III-C.

### B. Validation range of parameter sets

In the simulation of multiple parameter sets, specific conditions are imposed to define the validation range. This study focuses on workplaces with prevalent absenteeism, necessitating a significant occurrence of absences. Therefore, verified absence probabilities, represented by $q$, are set to 0.05, 0.10, and 0.15. Additionally, to address scenarios where an excessively large maximum acceptance count $m$ might lead to only employees with high acceptance levels, resulting in minimal the insufficient number of employees and task execution instability, conditions are added for the number $n_{high}$ of employees with high acceptance levels. Here, $F$ denotes the total number of absences over the entire period.

$$n_{high} m < F \tag{8}$$

TABLE III: PARAMETER SETS WITH THE LARGEST INSUFFICIENT NUMBER OF EMPLOYEES

| Rank | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $X$ | 50 | 50 | 50 | 50 | 50 |
| $d$ | 28 | 28 | 28 | 28 | 28 |
| $q$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| $m$ | 2 | 2 | 2 | 3 | 2 |
| $p_{low}$ | 0.05 | 0.10 | 0.10 | 0.05 | 0.10 |
| $p_{high}$ | 0.90 | 0.90 | 0.90 | 0.90 | 0.70 |
| $n_{low}$ | 35 | 40 | 35 | 35 | 35 |
| $n_{high}$ | 15 | 10 | 15 | 15 | 15 |
| $\zeta$ | 1.821 | 1.472 | 1.354 | 1.352 | 1.339 |

Furthermore, when $p_{low} \approx p_{high}$ it becomes challenging to express the difference in acceptance probabilities between employees. Therefore, the following equation must hold:

$$p_{low} \ll p_{high} \tag{9}$$

Furthermore, to address situations where employees with both high and low acceptance levels are reasonably mixed, the following equation must hold for $n_{low}$ and $n_{high}$:

$$n_{low} \gg 0 \tag{10}$$

$$n_{high} \gg 0 \tag{11}$$

Lastly, it is crucial to consider the relationship between the expected number of substitute attendances and the number of absences. If the expected number significantly surpasses the number of absences, addressing the insufficient number of employees may improve, even without altering the request order. Conversely, if the expected number is considerably lower than the number of absences, mitigating the insufficient number of employees becomes challenging, even with a change in request order. Thus, the verification focused on a range where the following equation holds:

$$1 < \frac{\frac{n_{low}}{n_{low}+n_{high}} c p_{low} + \frac{n_{high}}{n_{low}+n_{high}} c p_{high}}{\frac{F}{d}} < \beta \tag{12}$$

Here, $\beta$ is the threshold, and $c$ is the average number of substitute attendance candidates per time slot per day. In this study, $c$ is determined based on the average number of candidates derived from pre-generated shift schedules with no absences.

## *C. Experimental setup*

In Section III-A, we set the minimum (maximum) number of employees on duty for time slot $k$, $a_k$, $b_k$ uniformly as $a_1 = a_2 = a_3 = b_1 = b_2 = b_3 = 8$ for a straightforward comparison. Under these conditions, the total number of absences $F$ over the entire period, considering absence probabilities $q = 0.05, 0.10, 0.15$, is approximately $F = 33.6, 67.2, 100.8$, respectively. The maximum working days $e$ for each employee is set to 20, the maximum consecutive working days $r$ is set to 4, and the maximum consecutive working days for time slot 3 $s$ is set to 3. Table II provides details for the parameter sets explored under the conditions in Section IV-B. It is important to note that in this experiment, $\beta = 1.5, c = 14$ were set based on the conditions in Section IV-B. For each of the 340 parameter sets listed in Table II, a simulation of substitute attendance requests over the entire period was conducted 300 times, measuring the average daily insufficient personnel and the average daily number of requests from managers to employees.

Subsequently, we calculated the difference in the daily insufficient number of employees and the difference in the number of requests from managers to employees for each parameter set among the three validated request order determination strategies. The difference among strategies refers to the gap between the highest and lowest average values of the daily insufficient number of employees or requests. We will now discuss the top 5, bottom 5, and 5 around the median parameter sets where the difference in the insufficient number of employees or requests among strategies is the most significant.

In particular, for the top 5 and bottom 5, we will analyze the relationship between the daily insufficient number of employees and the number of requests. Based on the trials for all parameter sets, we will also discuss the trend in the evolution of the difference in the insufficient number of employees (requests) among strategies when arranged in descending request strategy, and verify the percentage of parameter sets where a significant difference occurs. Additionally, we will analyze the distribution of each parameter at that time and determine an appropriate degree of the polynomial approximation curve representing the overall trend through cross-validation.

Finally, for the parameter sets where the difference in the insufficient number of employees(requests) among strategies is the largest, the smallest, and around the median, we will measure and compare the average number of times employees attended as substitutes (accepted requests) and the average number of requests received by employees from managers over the entire period.

## *D. Result*

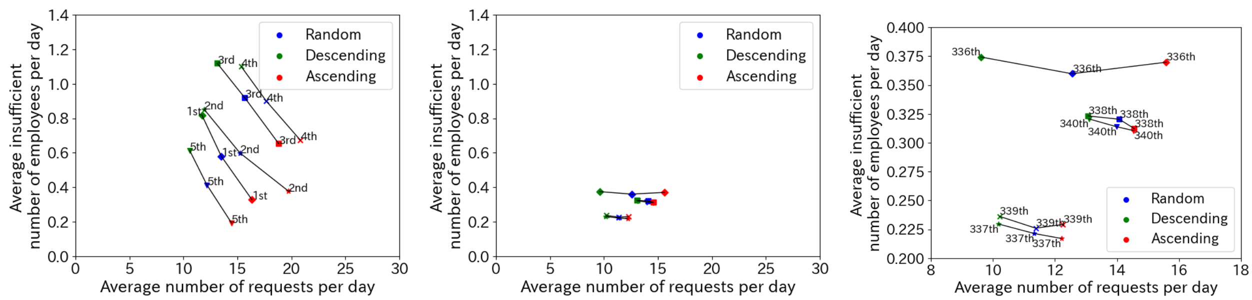
*1) Insufficient number of employees:* For the top 5 parameter sets with largest average the daily insufficient number of employees among 300 simulations, details are presented in Table III, where $\zeta$ represents the average daily insufficient number of employees. Notable characteristics leading to higher daily insufficient number of employees include a high absence probability $q$ (indicating more absences $F$), a small maximum acceptance count $m$, and relatively small $p_{low}$ with large $p_{high}$. The value of $n_{low}$ is 35 for all sets except the 2nd set.

*2) Difference in insufficient number of employees among strategies:* Table IV presents the top 5 parameter sets(1st-5th), the 5 sets around the median(169th-173rd) with the largest difference in the daily insufficient number of employees among strategies and the 5 parameter sets(336th-340th) with the smallest difference. The symbol $\delta$ represents the difference in the daily insufficient number of employees among strategies.

From Table IV, the trends for the top 5 parameter sets include a significant difference between $p_{low}$ and $p_{high}$, with the number of employees $n_{high}$ having high acceptance level set at 15, except for the 4th set. Additionally, the maximum

TABLE IV: PARAMETER SET WITH THE MOST SIGNIFICANT DIFFERENCE IN THE INSUFFICIENT NUMBER OF EMPLOYEES BETWEEN STRATEGIES, THE LEAST SIGNIFICANT DIFFERENCE, AND AN INTERMEDIATE LEVEL OF DIFFERENCE

| Rank | 1st | 2nd | 3rd | 4th | 5th | 169th | 170th | 171st | 172nd | 173rd | 336th | 337th | 338th | 339th | 340th |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X$ | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| $d$ | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| $q$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.10 | 0.15 | 0.15 | 0.15 | 0.10 | 0.05 | 0.10 | 0.15 | 0.10 | 0.15 |
| $m$ | 3 | 4 | 3 | 4 | 3 | 2 | 4 | 8 | 2 | 7 | 6 | 7 | 20 | 11 | 18 |
| $p_{low}$ | 0.15 | 0.10 | 0.10 | 0.10 | 0.20 | 0.15 | 0.10 | 0.10 | 0.10 | 0.20 | 0.15 | 0.25 | 0.20 | 0.25 | 0.15 |
| $p_{high}$ | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.50 | 0.70 | 0.70 | 0.50 | 0.90 | 0.60 | 0.50 | 0.50 | 0.50 | 0.50 |
| $n_{low}$ | 35 | 35 | 35 | 40 | 35 | 45 | 45 | 40 | 40 | 45 | 45 | 45 | 45 | 45 | 45 |
| $n_{high}$ | 15 | 15 | 15 | 10 | 15 | 5 | 5 | 10 | 10 | 5 | 5 | 5 | 5 | 5 | 5 |
| $\delta$ | 0.490 | 0.474 | 0.465 | 0.427 | 0.419 | 0.117 | 0.115 | 0.1149 | 0.1145 | 0.1145 | 0.014 | 0.012 | 0.0109 | 0.0102 | 0.0101 |




(a) Best5 (b) Worst5 (c) Worst5 expansion

Fig. 1: Relationship between insufficient number of employees and number of requests per day(Table IV).

TABLE V: VARIANCE(TABLE IV)

| | random | des | asc |
|---|---|---|---|
| 1st | 0.041 | 0.050 | 0.032 |
| 171st | 0.020 | 0.0185 | 0.013 |
| 340th | 0.016 | 0.0187 | 0.016 |

TABLE VI: AVERAGE(TABLE IV)

| | random | des | asc |
|---|---|---|---|
| 1st | 0.579 | 0.818 | 0.328 |
| 171st | 0.302 | 0.354 | 0.239 |
| 340th | 0.313 | 0.320 | 0.310 |

TABLE VII: MEDIAN(TABLE IV)

| | random | des | asc |
|---|---|---|---|
| 1st | 0.571 | 0.821 | 0.303 |
| 171st | 0.285 | 0.321 | 0.214 |
| 340th | 0.285 | 0.321 | 0.285 |

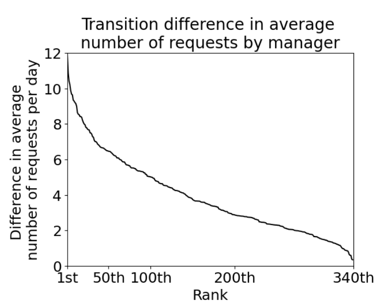



Fig. 2: Transition of difference in average insufficient number of employees.

acceptance count $m$ is relatively small compared to other parameter sets in the validation.

Conversely, Table IV shows trends for the bottom 5 parameter sets, indicating a smaller difference between $p_{low}$ and $p_{high}$" compared to other sets in the validation. Additionally, the number of employees $n_{low}$ with low acceptance probabilities is consistently 45 for all 5 parameter sets. Regarding the maximum acceptance count $m$," particularly in the 338th, 339th, and 340th sets, larger values are observed compared to other parameter sets in the validation. However, when looking at the values of $\delta$," the difference between the 336th and 340th sets is extremely small, with only 0.0039.

For the 1st set, 171st set, and 340th set (Table IV), the distribution of the daily insufficient number of employees in 300 trials for each strategy (random, descending, ascending request strategy) is presented in Table V for unbiased variance, Table VI for mean, and Table VII for median. In Table V, it can be observed that for all three sets (1st, 171st, 340th), the unbiased variance tends to be smaller for the ascending order strategy. The variance is larger for the 1st set, while for the 171st and 340th sets, the variance values are almost equal.

From Tables VI and VII, for the 1st set, there is little difference between the mean and median values for any strategy. On the other hand, for the 171st and 340th sets, the mean values are slightly higher than the medians, indicating a rightward skewness in the distribution.

From Table IV, the overall trend for the 5 parameter sets around the median indicates an intermediate nature compared to the top 5 and bottom 5. For the 169th and 172nd sets, although the maximum acceptance count $m$ is small, the difference between $p_{low}$ and $p_{high}$ is also small. On the other

TABLE VIII: QUANTILE OF $q$ DISTRIBUTION

| $q$ | Min | $Q_1$ | $Q_2$ | $Q_3$ | Max |
|---|---|---|---|---|---|
| 0.15 | 1 | 58 | 136 | 220 | 340 |
| 0.10 | 23 | 112.5 | 189.5 | 282.5 | 339 |
| 0.05 | 185 | 250 | 275 | 305 | 336 |

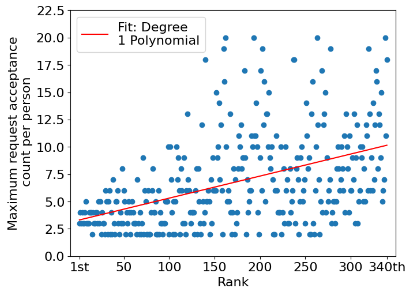



Fig. 3: Plots of $m$ distribution.

hand, for the 171st and 173rd sets, the difference between $p_{low}$ and $p_{high}$ is large, but the maximum acceptance count $m$ is also large. For the 170th set, the value of the maximum acceptance count $m$ is larger than that of the 169th and 172nd sets, and the difference between $p_{low}$ and $p_{high}$ is smaller compared to the 171st and 173rd sets.

Figure 1 illustrates the relationship between the daily insufficient number of employees and the number of requests for the top 5 and bottom 5 parameter sets with the largest difference in the insufficient number of employees. Notably, sets with a significant difference in the insufficient number of employees show almost twice the difference between descending and ascending request strategies. Conversely, sets with minimal difference in the insufficient number of employees, such as the 336th set, exhibit little difference in the number of requests.

Figure 2 depicts the trend in the difference in the daily insufficient number of employees among strategies for all validated parameter sets in descending request strategy. The decrease in the difference is significant up to around the 50th set. Parameter sets with a difference exceeding 0.4 constitute only around 2.0% of the total (1st to 7th), and those exceeding

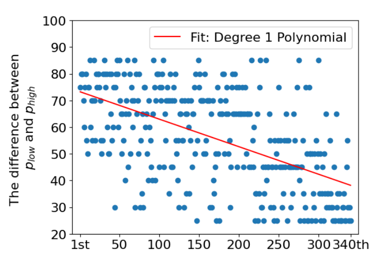



Fig. 4: Plots of distribution of the difference between $p_{low}$ and $p_{high}$.

TABLE IX: QUANTILE OF $n_{high}$ DISTRIBUTION

| $n_{high}$ | Min | $Q_1$ | $Q_2$ | $Q_3$ | Max |
|---|---|---|---|---|---|
| 15 | 1 | 23 | 47 | 88.75 | 229 |
| 10 | 4 | 60.5 | 110 | 185 | 324 |
| 5 | 56 | 174 | 237 | 293 | 340 |

TABLE X: PARAMETER SETS WITH THE LARGEST REQUEST FREQUENCY

| Rank | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $X$ | 50 | 50 | 50 | 50 | 50 |
| $d$ | 28 | 28 | 28 | 28 | 28 |
| $q$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| $m$ | 3 | 2 | 4 | 3 | 4 |
| $p_{low}$ | 0.05 | 0.05 | 0.10 | 0.10 | 0.05 |
| $p_{high}$ | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| $n_{low}$ | 35 | 35 | 40 | 40 | 35 |
| $n_{high}$ | 15 | 15 | 10 | 10 | 15 |
| $\eta$ | 18.098 | 18.003 | 17.949 | 17.918 | 17.763 |

0.3 account for approximately 8.8% (1st to 30th). Conversely, sets with a difference below 0.1 make up 43.5% of the total (193rd to 340th).

Table VIII displays quartiles, minimum, and maximum values of the absenteeism probability $q$ rank for each parameter set in descending request strategy of the difference $\delta$ in the insufficient number of employees between strategies. The table indicates that the difference in insufficient employees tends to increase with higher absenteeism probability, signifying more absences.

In Figure 3, the plot of the maximum acceptance count $m$ for each parameter set, arranged in descending request strategy of the insufficient number of employees difference between strategies, is presented. The regression line suggests that as the maximum acceptance count $m$ decreases, the difference in the insufficient number of employees between strategies tends to increase.

Additionally, Figure 4 shows the plot of the difference between acceptance probabilities $p_{low}$ and $p_{high}$ for each parameter set, ordered by the difference in the insufficient number of employees between strategies. The regression line illustrates that a larger difference between $p_{low}$ and $p_{high}$ corresponds to a greater difference in the insufficient number of employees between strategies.

Table IX presents quartiles, minimum, and maximum values of the rank of the number of employees $n_{high}$ with high acceptance levels, in descending request strategy of the difference in the insufficient number of employees between strategies. The table highlights that a higher number of employees with high acceptance levels contributes to a larger difference in the insufficient number of employees between strategies.

*3) Number of requests by manager:* Table X displays the top 5 parameter sets with the largest average number of daily requests in 300 simulations, denoted by $\eta$. Characteristics of sets with higher daily request numbers include a high absenteeism probability $q$, indicating a larger number of absences $F$, and a relatively small maximum acceptance count $m$. $p_{low}$ is small, $p_{high}$ is large, and $n_{low}$ is 40 for the 3rd and 4th sets and 35 for the others.

*4) Difference in number of requests among strategies:* Table XI shows the top 5 parameter sets (1st-5th), the 5 sets around the median (169th-173rd) with the largest differences in request numbers between strategies, and the 5 parameter sets (336th-340th) with the smallest difference, denoted as $\epsilon$. Among the top 5 sets, all have the smallest $p_{low}$ value

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TABLE XI: PARAMETER SET WITH THE MOST SIGNIFICANT DIFFERENCE IN THE NUMBER OF REQUEST BETWEEN STRATEGIES, THE LEAST SIGNIFICANT DIFFERENCE, AND AN INTERMEDIATE LEVEL OF DIFFERENCE

| Rank | 1st | 2nd | 3rd | 4th | 5th | 169th | 170th | 171st | 172nd | 173rd | 336th | 337th | 338th | 339th | 340th |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X$ | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| $d$ | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| $q$ | 0.15 | 0.15 | 0.10 | 0.10 | 0.10 | 0.10 | 0.15 | 0.05 | 0.15 | 0.10 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| $m$ | 6 | 5 | 6 | 4 | 5 | 4 | 10 | 2 | 3 | 7 | 2 | 2 | 2 | 2 | 2 |
| $p_{low}$ | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 | 0.20 | 0.05 | 0.15 | 0.15 | 0.25 | 0.25 | 0.20 | 0.25 | 0.25 |
| $p_{high}$ | 0.90 | 0.90 | 0.90 | 0.70 | 0.90 | 0.90 | 0.50 | 0.50 | 0.70 | 0.70 | 0.90 | 0.70 | 0.90 | 0.90 | 0.50 |
| $n_{low}$ | 35 | 35 | 40 | 35 | 40 | 45 | 40 | 45 | 40 | 45 | 40 | 45 | 45 | 45 | 45 |
| $n_{high}$ | 15 | 15 | 10 | 15 | 10 | 5 | 10 | 5 | 10 | 5 | 10 | 5 | 5 | 5 | 5 |
| $\epsilon$ | 11.917 | 10.872 | 10.415 | 10.220 | 9.878 | 3.461 | 3.447 | 3.421 | 3.387 | 3.384 | 0.635 | 0.594 | 0.583 | 0.373 | 0.340 |

TABLE XII: VARIANCE OF NUMBER OF REQUESTS(TABLE XI)

| | random | des | asc |
|---|---|---|---|
| 1st | 4.671 | 4.577 | 2.750 |
| 171st | 3.062 | 3.275 | 3.030 |
| 340th | 1.123 | 1.096 | 1.021 |

TABLE XIII: AVERAGE OF NUMBER OF REQUESTS(TABLE XI)

| | random | des | asc |
|---|---|---|---|
| 1st | 16.590 | 10.713 | 22.410 |
| 171st | 9.424 | 8.428 | 10.816 |
| 340th | 11.498 | 11.313 | 11.624 |

(0.05) except for the 4th set. Except for the 4th set, they also exhibit the largest $p_{high}$ values (0.90). The maximum acceptance count $m$ falls within intermediate values for these sets. Conversely, the bottom 5 sets, all with an employee absenteeism probability $q$ of 0.15, show a small difference between $p_{low}$ and $p_{high}$ values. The $n_{high}$ is 5 for all except the 336th set, and the maximum acceptance count $m$ is 2 in all five sets. The 5 sets near the median exhibit intermediate characteristics. For sets 169th, 171st, and 172nd, $m$ is relatively small, but the difference between $p_{low}$ and $p_{high}$ is large. For sets 171st and 173rd, the difference between $p_{low}$ and $p_{high}$ is significant, but $m$ is large. For set 170th, both $m$ and $p_{low}$ are large.

For the 1st, 171st, 340th paremeter sets in Table XI, the distribution of daily average requests for random, descending, and ascending request strategies is presented in Tables XII, XIII, and XIV, respectively. Table XII shows that, similar to daily insufficient employee numbers, the ascending request strategy has the smallest unbiased variance for all three sets (1st, 171st, and 340th). In random and descending request strategies, the 1st set has the largest variance, followed by 171st, while 340th has the smallest variance. Regarding mean values and medians (Tables XIII and XIV), the 1st set shows little difference, but for sets 171st and 340th, mean values are slightly higher than medians.

The relationship between daily insufficient personnel and the number of requests for the top 5 parameter sets with the largest difference and the bottom 5 parameter sets is shown in Figure 5. Notably, for parameter sets with a significant difference in the number of requests, the daily number of requests between descending and ascending request strategies differs approximately twofold. Conversely, for parameter sets with minimal differences in request counts, the occurrence of the daily insufficient number of employees is also limited.

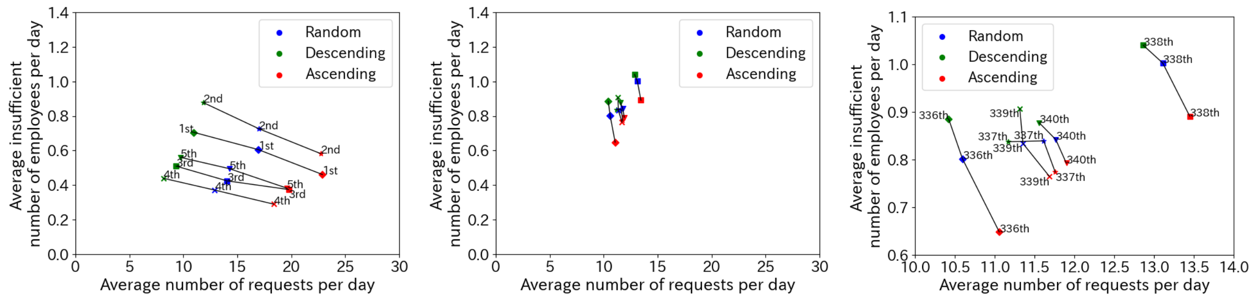
TABLE XIV: MEDIAN OF NUMBER OF REQUESTS(TABLE XI)

| | random | des | asc |
|---|---|---|---|
| 1st | 16.714 | 10.732 | 22.428 |
| 171st | 9.464 | 8.535 | 10.714 |
| 340th | 11.482 | 11.321 | 11.678 |

Figure 6 illustrates the transition of the difference in the number of requests between strategies, sorted in descending order for all validated parameter sets. Similar to the trend observed in Figure 2, there is a significant decrease in the range of 1st to around 50th in Figure 6. For instance, parameter sets with a difference in the number of requests between strategies exceeding 10 represent approximately 1.1% of the total (1st to 4th), and even when limited to a difference of 8 or more, it accounts for around 5.8% of the total (1st to 20th). Conversely, parameter sets with a difference of 4 or less constitute 58.5% of the total (142nd to 340th).

Table XV displays quartiles, minimum, and maximum values of absenteeism probability $q$ ranks for each parameter set, sorted by the difference in manager-requested counts between strategies. The trend suggests that, overall, lower absenteeism probabilities are associated with larger differences in request numbers, though exceptions exist. Next, Figure 7 presents the plot of maximum acceptance count $m$ ranks for each parameter set, ordered by the difference in manager-requested counts. The red line indicates a fifth-degree approximation curve. Notably, both very large and very small $m$ values result in smaller differences in request numbers, with the most significant difference occurring at intermediate levels (around 5 to 6). Furthermore, Figure 8 illustrates the plot of the difference between acceptance probabilities $p_{low}$ and $p_{high}$ for each parameter set, ordered by the difference in manager-requested counts. The red line represents the regression line, showing that a larger difference between $p_{low}$ and $p_{high}$ corresponds to a larger difference in request numbers between strategies. Table XVI presents the quartiles, minimum, and maximum values of the ranks of the number of employees with high acceptance levels $n_{high}$ for each parameter set, ordered by the magnitude of the difference in the number of requests made by managers between strategies. It can be observed that a larger number of employees with high acceptance probabilities corresponds to a larger difference in the number of requests between strategies.

*5) Substitute attendance count of employees and the number of received requests:* Tables XVII, XVIII, and XIX show the




(a) Best5 (b) Worst5 (c) Worst5 expansion

Fig. 5: Relationship between insufficient number of employees and number of requests per day (Table XI).

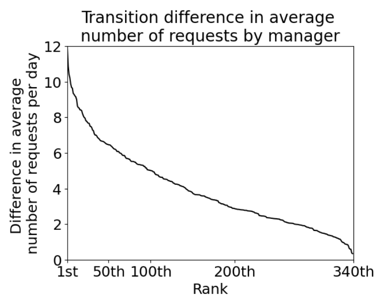



Fig. 6: Transition of difference in average number of requests by manager.

TABLE XV: QUANTILE OF $q$ DISTRIBUTION

| $q$ | Min | $Q_1$ | $Q_2$ | $Q_3$ | Max |
|---|---|---|---|---|---|
| 0.15 | 1 | 108 | 199 | 275 | 340 |
| 0.10 | 3 | 90.75 | 160.0 | 222.75 | 334 |
| 0.05 | 31 | 53 | 79 | 111 | 171 |

average number of employees based on substitute attendances over 300 trials for the 1st, 171st, and 340th parameter sets (Tables IV). In Table XVII, employees with 3 substitute attendances are the most numerous regardless of the request strategy (random, descending, or ascending). Conversely, Tables XVIII and XIX indicate that the descending request strategy yields the largest proportion of employees with more substitute attendances, while the ascending strategy shows the smallest proportion.

Tables XX, XXI, and XXII display the average number of requests received by each employee from managers (regardless of acceptance) over 300 trials for the 1st, 171st, and 340th parameter sets (Tables IV). Across all three sets, the ascending request strategy results in a larger proportion of employees receiving more requests. In contrast, the descending strategy leads to more employees receiving fewer requests, with the random strategy showing an intermediate trend.

Tables XXIII, XXIV, and XXV show average employee counts for substitute attendances in the 1st, 171st, and 340th parameter sets from Table XI over 300 trials. In the 1st set, with a maximum acceptance count of 6, substitute attendances range from 0 to 6 per employee, while in the 171st and 340th sets, this range is 0 to 2. Table XXIII highlights that the descending request strategy leads to more substitute attendances for employees in the 1st set. However, the difference between strategies is less pronounced in Tables XXIV and XXV, likely due to smaller maximum acceptance counts in these cases.

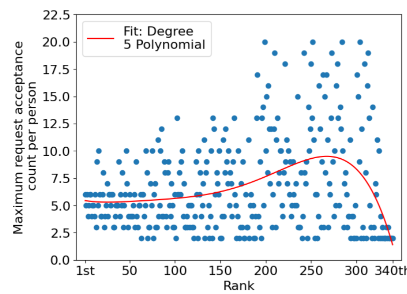



Fig. 7: Plots of $m$ distribution.

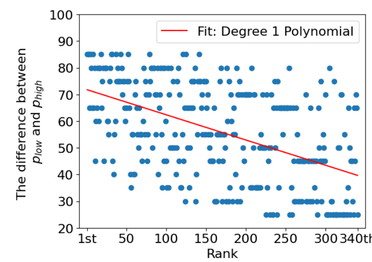



Fig. 8: Plots of distribution of the difference between $p_{low}$ and $p_{high}$.

Tables XXVI, XXVII, and XXVIII present the average number of requests received by each employee from managers (regardless of acceptance) during 300 trials for the 1st, 171st, and 340th parameter sets (Tables XI). In all three parameter sets, it is evident that, when the ascending request strategy is employed, the proportion of employees receiving a higher number of requests from managers is larger.

### *E. Consideration*

Table III highlights that insufficient employee numbers are more common with high absenteeism probability ($q$) and a low maximum acceptance count ($m$). This is likely due to the challenge of securing replacement workers for frequently absent employees when flexibility is limited. Furthermore, a significant gap between acceptance probabilities ($p_{low}$ and

TABLE XVI: QUANTILE OF $n_{high}$ DISTRIBUTION

| $n_{high}$ | Min | $Q_1$ | $Q_2$ | $Q_3$ | Max |
|---|---|---|---|---|---|
| 15 | 1 | 25.25 | 67.5 | 137.25 | 308 |
| 10 | 3 | 61 | 123 | 181.5 | 336 |
| 5 | 31 | 156 | 227 | 285 | 340 |

TABLE XVII: NUMBER OF EMPLOYEES BY FREQUENCY OF SUBSTITUTE ATTENDANCE DURING PERIOD(TABLE IV, 1ST)

| times | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| random | 10.47 | 13.03 | 8.83 | 17.66 |
| des | 12.76 | 13.41 | 7.31 | 16.50 |
| asc | 7.51 | 11.98 | 12.27 | 18.23 |

$p_{high}$), coupled with a substantial number of employees with high acceptance probabilities ($n_{high}$), leads to noticeable shortages in employee availability. This suggests that in scenarios with frequent absences, restricted employee availability for substitute work (due to workplace rules or other factors), a relatively high acceptance rate (around 30Conversely, observing opposite trends for each parameter may help mitigate the occurrence of a shortage of employees. In workplaces with these characteristics, Figure 1 highlights a significant employee shortage difference between descending and ascending request strategies. Increasing requests in the ascending strategy notably reduces employee shortages. Prioritizing shortage reduction favors the ascending strategy, while opting for the descending strategy is advisable for reducing managerial burden. However, Tables XX through XXII show that the ascending request strategy often results in more requests received by employees. In situations where excessive requests may impact employee motivation negatively, adopting this strategy may not be ideal. Conversely, Tables XVII through XIX suggest that the descending request strategy tends to lead to more substitute work occurrences for employees, potentially indicating better motivation retention.

In workplaces with infrequent absences and around 10However, Tables XVII, XVIII, XIX, XXIII, XXIV, and XXV indicate that the descending request strategy slightly increases the proportion of employees with more substitute work occurrences. This may be desirable, reflecting sustained employee motivation despite frequent substitute work. In cases with no significant difference in request counts between strategies (e.g., 337th to 340th sets), there's little distinction in the shortage of employees and the manager's request count. Therefore,

TABLE XVIII: NUMBER OF EMPLOYEES BY FREQUENCY OF SUBSTITUTE ATTENDANCE DURING PERIOD(TABLE IV, 171ST)

| times | 0-2 | 3-4 | 5-6 | 7-8 |
|---|---|---|---|---|
| random | 35.87 | 10.37 | 3.12 | 0.62 |
| des | 38.03 | 5.04 | 3.99 | 2.93 |
| asc | 34.45 | 13.66 | 1.79 | 0.08 |

TABLE XIX: NUMBER OF EMPLOYEES BY FREQUENCY OF SUBSTITUTE ATTENDANCE DURING PERIOD(TABLE IV, 340TH)

| times | 0-5 | 6-9 | 10-12 | 13-18 |
|---|---|---|---|---|
| random | 49.35 | 0.64 | 0.0 | 0.0 |
| des | 47.83 | 2.09 | 0.08 | 0.0 |
| asc | 49.49 | 0.50 | 0.0 | 0.0 |

TABLE XX: NUMBER OF EMPLOYEES BY FREQUENCY OF REQUESTS RECEIVED DURING PERIOD(TABLE IV, 1ST)

| times | 0-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 |
|---|---|---|---|---|---|---|
| random | 19.87 | 18.88 | 9.60 | 1.53 | 0.09 | 0.003 |
| des | 23.85 | 19.49 | 6.02 | 0.59 | 0.03 | 0.00 |
| asc | 17.69 | 12.12 | 13.52 | 5.77 | 0.84 | 0.04 |

TABLE XXI: NUMBER OF EMPLOYEES BY FREQUENCY OF REQUESTS RECEIVED DURING PERIOD(TABLE IV, 171ST)

| times | 0-4 | 5-9 | 10-14 | 15-19 | 20-24 | 25-27 |
|---|---|---|---|---|---|---|
| random | 9.81 | 25.01 | 13.01 | 2.04 | 0.10 | 0.00 |
| des | 17.97 | 22.78 | 7.12 | 1.99 | 0.12 | 0.00 |
| asc | 10.78 | 16.24 | 16.27 | 5.93 | 0.74 | 0.01 |

TABLE XXII: NUMBER OF EMPLOYEES BY FREQUENCY OF REQUESTS RECEIVED DURING PERIOD(TABLE IV, 340TH)

| times | 0-5 | 6-11 | 12-17 | 18-23 | 24-29 | 30-33 |
|---|---|---|---|---|---|---|
| random | 14.62 | 27.83 | 7.20 | 0.33 | 0.003 | 0.00 |
| des | 18.37 | 25.51 | 4.90 | 1.06 | 0.13 | 0.006 |
| asc | 13.03 | 26.38 | 9.16 | 0.52 | 0.00 | 0.00 |

TABLE XXIII: NUMBER OF EMPLOYEES BY FREQUENCY OF SUBSTITUTE ATTENDANCE DURING PERIOD(TABLE XI, 1ST)

| times | 0 | 1-2 | 3-4 | 5-6 |
|---|---|---|---|---|
| random | 22.23 | 14.40 | 4.51 | 8.84 |
| des | 27.62 | 9.05 | 3.15 | 10.16 |
| asc | 17.14 | 19.35 | 6.57 | 6.93 |

TABLE XXIV: NUMBER OF EMPLOYEES BY FREQUENCY OF SUBSTITUTE ATTENDANCE DURING PERIOD(TABLE IV, 171ST)

| times | 0 | 1 | 2 |
|---|---|---|---|
| random | 34.68 | 10.48 | 4.82 |
| des | 35.77 | 9.13 | 5.09 |
| asc | 33.81 | 11.73 | 4.44 |

TABLE XXV: NUMBER OF EMPLOYEES BY FREQUENCY OF SUBSTITUTE ATTENDANCE DURING PERIOD(TABLE IV, 340TH)

| times | 0 | 1 | 2 |
|---|---|---|---|
| random | 6.03 | 10.92 | 33.05 |
| des | 6.15 | 11.07 | 32.77 |
| asc | 5.70 | 10.56 | 33.73 |

TABLE XXVI: NUMBER OF EMPLOYEES BY FREQUENCY OF REQUESTS RECEIVED DURING PERIOD(TABLE IV, 1ST)

| times | 0-4 | 5-9 | 10-14 | 15-19 | 20-24 | 25-28 |
|---|---|---|---|---|---|---|
| random | 5.93 | 21.52 | 16.97 | 4.76 | 0.76 | 0.03 |
| des | 16.96 | 26.07 | 6.73 | 0.22 | 0.006 | 0.0 |
| asc | 5.72 | 12.95 | 11.62 | 11.56 | 6.38 | 1.47 |

TABLE XXVII: NUMBER OF EMPLOYEES BY FREQUENCY OF REQUESTS RECEIVED DURING PERIOD(TABLE IV, 171ST)

| times | 0-3 | 4-6 | 7-9 | 10-12 | 13-15 | 16-20 |
|---|---|---|---|---|---|---|
| random | 14.37 | 20.17 | 11.67 | 3.28 | 0.45 | 0.04 |
| des | 17.25 | 21.19 | 9.41 | 1.95 | 0.18 | 0.00 |
| asc | 10.94 | 18.10 | 14.08 | 5.60 | 1.10 | 0.15 |

TABLE XXVIII: NUMBER OF EMPLOYEES BY FREQUENCY OF REQUESTS RECEIVED DURING PERIOD(TABLE IV, 340TH)

| times | 0-3 | 4-7 | 8-11 | 12-15 | 16-19 | 20-26 |
|---|---|---|---|---|---|---|
| random | 9.89 | 23.48 | 12.48 | 3.51 | 0.58 | 0.04 |
| des | 10.33 | 23.68 | 12.17 | 3.30 | 0.38 | 0.11 |
| asc | 10.89 | 21.88 | 12.31 | 4.16 | 0.70 | 0.04 |

choosing the ascending request strategy can address imbalances in substitute work occurrences among employees, while the descending strategy is preferable for reducing the number of requests received by employees. Table X highlights that higher manager-to-employee request numbers coincide with elevated absenteeism probability ($q$), necessitating more substitute attendance. Even in workplaces with low absenteeism probability, notable differences in request numbers persist. Figure 5 indicates significant contrasts between descending and ascending request strategies, with the former recommended for reducing managerial burden and the latter for addressing insufficient employees. However, the effectiveness of the ascending strategy may be limited in certain scenarios (e.g., cases 1 to 5 in Figure 5). Further analysis is needed to assess the correlation between request differences and insufficient employee numbers. Additionally, caution is advised regarding the potential impact on employee motivation, particularly with the descending request strategy favoring individuals with more substitute attendances. In such cases, the random request strategy may offer a preferable alternative, aligning closely with trends observed in both requests and insufficient numbers compared to the descending strategy. Conversely, when the maximum acceptance count ($m$) is either too small or too large, and there is minimal difference between acceptance probabilities ($p_{low}$ and $p_{high}$), with few employees having high acceptance probabilities ($n_{high}$), there is little to no notable difference in the number of requests from managers across strategies. In such cases, Figure 5 suggests adopting the ascending request strategy, which prioritizes reducing the insufficient number of employees. However, it is important to consider that the ascending request strategy may lead to an increase in the number of requests accepted by employees. Thus, in situations where the rise in requests may not significantly impact employee motivation, opting for the ascending request strategy to mitigate the insufficient number of employees is advisable.

## V. Conclusion

This paper presents a simulation model for substitute attendance requests, exploring three request order strategies: random, descending, and ascending. Our findings indicate that in workplaces with high absenteeism probability and specific characteristics, the ascending strategy effectively reduces employee shortages. Conversely, the descending strategy is effective for reducing managerial burden in workplaces with the opposite trend. In scenarios influenced by various factors, the descending or random strategies prove effective for reducing managerial burden, while the ascending strategy is suitable for mitigating employee shortages in workplaces with opposing trends.

Future research should focus on developing substitute shift request strategies based on easily observable managerial information, including past substitute shift counts and potential future availability, alongside employee acceptance probabilities.

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