algorithms

Article

A Practical Staff Scheduling Strategy Considering Various Types of Employment in the Construction Industry

Chan Hee Park and Young Dae Ko *

Department of Hotel and Tourism Management, College of Hospitality and Tourism, Sejong University, 209 Neungdong-ro, Seoul 05006, Korea
* Correspondence: youngdae.ko@sejong.ac.kr; Tel.: +82-10-4725-3480

Abstract: The Korean government implemented a 52-h workweek policy for employees' welfare. Consequently, companies face workforce availability reduction with the same number of employees. That is, labor-dependent companies suffer from workforce shortage. To handle the workforce shortage, they increase irregular employees who are paid relatively less. However, the problem of 'no-show', due to the stochastic characteristics of irregular employee's absence, happens. Therefore, this study aims to propose a staff scheduling strategy considering irregular employee absence and a new labor policy by using linear programming. By deriving a deterministic staff schedule through system parameters derived from the features and rules of an actual company in the numerical experiment, the practicality and applicability of the developed mathematical model are proven. Furthermore, through sensitivity analysis and simulation considering the stochastic characteristics of absences, various proactive cases are provided. Through the proactive cases, the influence of the change of the average percent of irregular employees' absences on the total labor costs and staff schedules and the expected number who would not come to work could be given when assuming the application in practice. This finding can help decision-makers prepare precautious measures, such as assigning extra employees in case of an irregular employee's absence.

Keywords: construction industry; irregular employees; staff scheduling; mathematical model; business level strategies; decision-making; organizational effectiveness

Citation: Park, C.H.; Ko, Y.D. A Practical Staff Scheduling Strategy Considering Various Types of Employment in the Construction Industry. *Algorithms* **2022**, *15*, 321. https://doi.org/10.3390/a15090321

Academic Editors: Francisco Saldanha da Gama and Frank Werner

Received: 21 July 2022
Accepted: 6 September 2022
Published: 9 September 2022

1. Introduction

The construction industry plays a significant role in economic growth [1]. Korea has also developed its economy along with the growth of the construction industry [2]. However, as presented in Figure 1, based on the 2020 Construction Policy Review by the Construction Policy Institute of Korea, the Korean construction industry has not contributed to economic growth since 2017. Moreover, the construction industry has hindered economic growth since 2018 due to problems such as workforce shortage and reduction in investment. According to the Ministry of Employment and Labor, the safety problem and low wage levels are the main reasons companies cannot employ new employees on construction sites. As for the safety problem, about 50 percent of occupational accidents that lead to death takes place in the construction industry. Regarding the wage level, employees in the construction industry are paid 26.1 percent lower than employees in the manufacturing industry. Even compared to the average rate of all industries, it is 15 percent lower [3]. For those reasons, workforce shortage happens in the construction industry in Korea. According to [4], the number of lacking employees on construction sites will increase to 96 thousand in 2024 from 83 thousand in 2020.

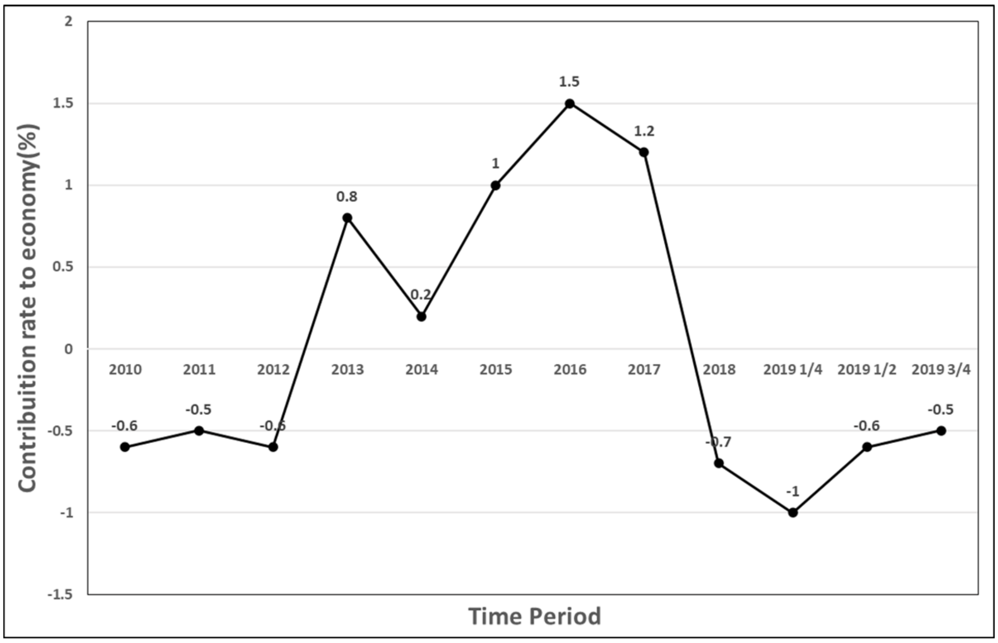

Figure 1. Contribution of the construction industry to the economic growth.

To solve the above problems, the government made the policy of the 52-h workweek and expanded hygiene facilities to improve the workplace environment. The 52-h workweek policy is a workhour limit for the employee's welfare. Due to this policy, each employee works 8 to 12 h a day and they cannot work more than 52 h a week. As a result, the company that finishes jobs by employing a small number of people and making them work for more than 52 h a week faces a crisis. That is, when a company needs to work for 70 h, it is more beneficial for them to make one employee work more by paying the extra cost to him/her than employ two employees and make each work 35 h. Moreover, they face workforce availability reduction to the same number of employees compared to before the change of the labor policy. Because of this situation, it is more important to consider human resource management to save labor costs and yield companies' performances [5].

About 50 percent are irregular employees out of the total workforce according to the statistics data from the Korean bank. The reason the percent of irregular employees is high is that many people do not want to be employed in the construction industry due to the possible dangers that can lead to death or disability [6]. In addition, if they employ regular employees, they need to keep paying for them even when they do not have work because of the difficulty of firing them. Due to this, construction companies suffer from workforce shortages, which is regarded as one of the most serious problems in all industries [7]. Moreover, companies want to employ irregular employees, including foreign employees, from an outsourcing company to reduce costs due to an increase in the labor cost [8]. According to [9], foreign employees account for 19.5 percent of the whole workforce size in the construction industry. In addition, it is expected that irregular foreign employees continue to increase. The government presented that about 57 thousand is the proper number of foreign employees in 2019. However, the number of foreign employees was about 210 thousand in the same year [10]. That is, the Korean construction industry faces a situation that has no choice but to employ a greater number of irregular foreign employees.

Several countries already use irregular employees to deal with the workforce shortage. For instance, Malaysia has already been using the irregular foreign workforce actively to manage the workforce shortage problem [11]. Furthermore, a portion of temporary jobs is increasing in the UK labor market [12]. Employing irregular foreign employees can be a realistic way to respond to the workforce shortage. However, it is important to know and understand the Korean way of using irregular employees. Most irregular employees are used in the way of getting paid daily. It is thought that this feature of the way of using irregular employees would be different from other countries that normally contract irregular employees and use them during the contracted period. However, because of the way of using irregular employees, irregular employees do not have loyalty, thus they also have low responsibility for working. In addition, they could have different irregular employees every day because they are normally contracted daily. Thus, they have difficulty keeping track of irregular employees and giving them penalties even when they make trouble due to a daily contract. These issues make it difficult for companies to conduct human resource management efficiently.

This paper considers the actual situation of the construction industry in Korea, such as the workforce shortage due to an increase in labor costs and workforce availability reduction by the change of the labor policy. The main thing considered in the paper is 'no-show', which is a real problem of the actual company that employed irregular employees to deal with the workforce shortage problem. Despite the no-show of irregular employees, it is difficult for the company to control irregular employees, since the authority of giving penalties normally belongs to their outsourcing company in Korea. Nevertheless, the reason a company uses irregular employees is because of lower labor costs than local regular employees. Therefore, the company needs to respond to the unexpected situation that irregular employees suddenly do not come to work. To achieve this, this research uses linear programming to derive a deterministic staff schedule considering the average percent of irregular employee absences. This can be one of the proactive measures to respond to the stochastic characteristics of an irregular employee's absence. Moreover, the simulation of a deterministic staff schedule is conducted to figure out what expectedly happens when assuming the application to a company in practice. Consequently, the performance of how well a staff schedule works is evaluated, and how many irregular employees do not come to work is expected. These can play a role as basic data that help managers decide on a staff schedule.

2. Literature Review

The method suggested in this research is to minimize the total labor cost of a construction company by deriving a deterministic staff schedule. Human resource is crucial in many operations that are heavily labor-oriented. In addition, it is typically one of the most expensive resources of a company [13,14]. That means that human resources are regarded as one of the most important factors to manage in every business. Edie [15] conducted the first research on a quantitative approach to a solution for staff scheduling problems. After this study, a variety of research was conducted in many different industries. Van den Bergh et al. [16] defined three main staff scheduling parts, namely shift scheduling, days off scheduling, and tour scheduling. Shift scheduling involves scheduling across a daily planning horizon, and one worker has just one shift a day. Days off scheduling is about the schedule of the day off for each worker. Tour scheduling is a combination of shift scheduling and days-off scheduling. Moreover, Ganguly and Nandi [17] revealed that staff scheduling is important to meet demands. In this paper, forecasting models, such as Analysis of Variance (ANOVA) and Auto Regressive Integrated Moving Average (ARIMA) were utilized. The demands derived from forecasting models were used for the mathematical model as input parameters to derive an optimal solution for staff scheduling. Furthermore, Maenhout and Vanhoucke [18] suggested a staffing and shift scheduling approach for nurses in the hospital. In this paper, the mathematical model was suggested for a new integrative nurse staff scheduling while considering the impact of several personnel policies on staffing level decisions to obtain an allocation of nurses. Ásgeirsson [19] conducted research on staff scheduling by using metaheuristic algorithms to consider the requests of employees. As a result, fair and feasible schedules were generated for staff scheduling. To summarize, various studies have proved that staff scheduling is beneficial for a company with a shifting policy to minimize labor costs.

The construction industry is interested in scheduling research to assign employees well. Memon and Zin [20] reported the status of resource-driven scheduling implementation in the Malaysian construction industry. It was revealed that about 60% of construction companies used scheduling to meet the construction project deadline under the limits of resource availability. Even though there are several constraints against using staff scheduling, such as high cost, and lack of understanding for scheduling, the importance of scheduling was proved in that many tried to have scheduling. Al-Rawi and Mukherjee [21] focused on a constructive method to solve labor scheduling problems encountered in a construction company. The linear programming technique was used to suggest estimated labor costs for a week and the conditions of part-time labor in each shift. Consequently, the organization could produce a new schedule each week while minimizing labor costs and maximizing labor preferences. Between a diversity of businesses, the hospitality industry is similar to the construction industry in terms of the labor-dependency. Rocha et al. [22] performed research on the optimization of staff schedules for a hotel in Turkey. They handled the problem through operation research (OR). As a result, they reduced the labor costs and the number of employees to finish their work during the same period. Kaya and Dağdeviren [23] studied the optimal allocation of employees to jobs while minimizing total daily labor costs. It proposed a Pareto multistage decision-based genetic algorithm (P-mdGA). As a result, this method helped managers of hotels in need of automatic support to effectively allocate hotel staff to jobs. Azadeh et al. [24] proved that airline crew assignment to flights can minimize total cost. A particle swarm optimization (PSO) algorithm with a local search heuristic was applied to derive a solution for crew scheduling. Consequently, the proposed hybrid PSO algorithm helped assign crew members to the flight while minimizing the total cost.

Not only labor costs but also the welfare of employees, such as workplace environment improvement and policy, have a huge influence on the construction industry. Much research regarding welfare for employees has been conducted in many different industries. Asensio-Cuesta et al. [25] developed the models for job rotation schedules as an aspect of welfare for staff, such as assignments to various jobs considering their skills and knowledge. A multi-criteria genetic algorithm is employed to provide a solution for both workers and management. Therefore, the model prevented reducing fatigue and increased job satisfaction and morale while giving a solution to job rotation scheduling. Ruiz-Torres et al. [26] performed research on scheduling problems considering worker satisfaction to contribute to enlargement in the field of staff scheduling. Metrics of job preference and desirable job variety were used for job satisfaction in scheduling problems. As a result, this paper generated an optimal solution for staff scheduling, considering the job satisfaction of employees. Furthermore, Stolletz and Brunner [27] studied an optimal shift scheduling solution for physicians in hospitals while considering preference, labor agreement, and fairness. In this paper, all constraints were modeled within the linear program (LP). As a result, this model provided a solution that takes fairness between physicians' shifts into consideration to minimize the paid-out hours under the restrictions given by the labor agreement. Shuib and Kamarudin [28] proposed a Binary Integer Goal Programming (BGP) model and a mathematical model to determine an optimal staff schedule at the power station. In addition, this research identified the main criteria and conditions for the BGP model. Consequently, the suggested method generated an optimal staff scheduling solution considering employees' day-off preferences by using MATLAB while focusing on three processes, which were demand modeling, shift scheduling, and day-off scheduling.

To improve the practicality, the uncertainty of irregular employees should be reflected when developing a staff scheduling strategy. Several studies considered the uncertainty of irregular employees. Research on workforce scheduling that considers the unpredictable employee's absence was conducted to guarantee sufficient coverage in medical facilities. Becker et al. [29] proposed integer programming that considers assigning ex-post duties. This paper proved the practicality of the developed models by applying them to local medical facilities in practice. As a result, staff scheduling complexity was reduced. Ingels and Maenhout [30] stated that many organizations make staff schedules under a deterministic operating environment. However, the stochastic environment, such as employee absence, occurs. To manage this uncertainty, this paper proposed a proactive approach to respond to schedule disruptions. By comparing a diversity of the proactive strategies, a proposed preemptive programming approach in this paper was assessed. Steenweg et al. [31] mentioned that short-term uncertainty in the workforce causes gaps between the planned and real shift schedule. Therefore, the unpredictable absence of employees should be considered when deciding on shift scheduling. This paper suggested a framework that can assign heterogeneously skilled employees to jobs optimally to respond to sudden absence. For this framework, the workforce availability was modeled by the stochastic simulation. As a result, the practicality of the framework that can provide efficient shift scheduling was proved by applying it to the actual cases.

This paper also considers the uncertainty of employees, especially irregular employee absence in the construction industry. Many studies about staff scheduling that handle the uncertain nature of employees suggested stochastic modeling. In addition, other studies proposed the strategies for assignment of skilled employees to shift to fill in the absence. However, this paper develops a mathematical model that derives a deterministic staff schedule by considering the average percent of irregular employees' absences. This is because the expected average percent of irregular employees' absences could be different from the actual average percent of their absences in practice. That is, even a staff schedule derived from the stochastic modeling cannot ensure that all irregular employees follow a staff schedule because it is performed only with reliance on the probability of absence. Therefore, this paper focuses on providing various proactive cases by deriving a deterministic staff schedule and conducting a simulation about it to evaluate performance. Consequently, the simulation helps a company expect how many irregular employees would not come to work when applying a deterministic staff schedule to a company. However, this cannot also guarantee that all irregular employees follow a staff schedule well because the possibility of their absences still exists. However, deriving a deterministic staff schedule and simulating it can contribute to providing a systematic procedure to manage the sudden absences of irregular employees. Therefore, this procedure can help managers prepare the precautious measures to rapidly respond to irregular employee absence.

3. Mathematical Formulation

3.1. Problem Description

Companies in the construction industry suffer from workforce shortage problems due to the 52-h workweek policy and a no-show by irregular employees. Before the explanation of the problem description in detail, irregular employees that are often shown in this paper are defined as foreign and local irregular employees who do not belong to a company and are paid daily. They are not part-time workers. Under the 52-h workweek policy, each employee can work 8 to 12 h a day and cannot exceed to work 52 h a week. In addition, if they work more than 8 h a day, it is regarded as overtime work. Along with the government policy, irregular employee absence worsens the workforce shortage. According to the managers of the construction company considered in this paper, the average percent of irregular employee absence is from 20% to 30% per day. As a result, this company often faces workforce availability reduction. To consider this uncertainty of irregular employee absence, the mathematical model introduces the average percent of irregular employee absence to derive a conservative and deterministic staff schedule that assumes they normally do not come to work according to their absence percent. However, the percent of irregular employees' absences is not constant in the real world. It is always stochastic. Thus, this paper performs the simulation of a derived staff schedule to consider the stochastic situation of irregular employees' absences. Furthermore, by changing the average percent of irregular employee absence, the change in total labor cost and staff schedules are examined depending on the percent of irregular employee absence more closely through sensitivity. Additionally, there are two types of jobs. There are four workplaces, namely the first floor, the second floor, open storage, and the office. Moreover, this company always needs more than 45 employees and more than 18 employees during the daytime and nighttime per day. To sum up, by conducting several numerical experiments in this paper, it is expected to provide proactive cases for a staff schedule considering the stochastic characteristics of irregular employee absence under the new labor policy in Korea.

3.2. Notation

3.2.1. Known Parameters

This paper derives a conservative and deterministic solution for a staff schedule that can minimize the total labor cost considering the new labor policy and the average percent of irregular employee absence. The following notations in Table 1 are composed of elements regarding the construction industry and the company's rules.

Table 1. Known parameters.

Variables	Meaning
I	Set for employees, including regular and irregular workers, $i \in I$
Pt	Set for irregular employees, such as foreign workers and sub-contractors, $pt \in Pt$
Ep	Set for regular employees, $ep \in Ep$
M	Set for managers, $m \in M$
P	Set for workplaces, $p \in P$
F	Set for floors excluding any other workplaces, $f \in F$
J	Set for jobs, $j \in J$
D	Set for days, $d \in D$
N	Set for weeks, $n \in N$
W_n	Set for days of the nth week
D_{sun}	Set for Sundays
D_{work}	Set for workdays
$cost_{id}$	Cost for regular employees i on day d (USD/day)
$hours_{i,d}$	Workhour for regular employees i on day d (hour)
$partcost_{pt,d}$	Cost for irregular employees pt on day (USD/day)
$parthours_{pt,d}$	Workhour for irregular employees pt on day d (hour)
$overcost_{i,d}$	Overtime work cost for irregular employees i on day d (USD/day)
$overhours_{i,d}$	Overtime workhour for irregular employees i on day d (hour)
min_d	Minimum number of needed workers on day d during daytime
$overmin_d$	Minimum number of needed workers on day d during nighttime
A_d	The average percent of irregular employees' absences on day d

3.2.2. Decision Variables

The decision variables in Table 2 for this mathematical model show the allocation of the employee to a specific workplace on a certain day.

Table 2. Decision Variables.

Variables	Meaning
$X_{i,j,p,d}$:	It becomes 1, if regular employee i is assigned to job j at workplace p on day d, otherwise 0
$Y_{i,j,p,d}$	It becomes 1, if irregular employee i is assigned to job j at workplace p on day d, otherwise 0
$R_{i,j,p,d}$	It becomes 1, if irregular employee i is assigned to job j at workplace p on day d after considering absence, otherwise 0
$O_{i,j,p,d}$	It becomes 1, if regular employee i is assigned to job j at workplace p on day d during nighttime, otherwise 0

3.3. Mathematical Model

Equation (1) is an objective function that minimizes the total labor cost. It consists of the sum of regular employees' total labor costs, the sum of irregular employees' total labor costs, and the sum of total overtime work costs:

$$\sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{d\in D} Cost_{id}\times X_{ijpd}+\sum_{i\in Pt}\sum_{j\in J}\sum_{p\in P}\sum_{d\in D} Partcost_{id}\times R_{ijpd}+ \sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{d\in D} Overcost_{id}\times O_{ijpd} \quad (1)$$

3.3.1. Constraints for Staff Scheduling during Daytime

Equations (2) and (3) represent the relationship between decision variables $R_{i,j,p,d}$ and $Y_{i,j,p,d}$. The actual number of irregular employees is decided by Equation (2) which multiplies the number of irregular workers following the schedules without absence by A_d. Equation (3) determines value of decision variable $R_{i,j,p,d}$. $R_{i,j,p,d}$ can be 1 when decision variable $Y_{i,j,p,d}$ is 1:

$$\sum_{i\in Pt}\sum_{j\in J}\sum_{p\in P} R_{ijpd}\le\sum_{i\in Pt}\sum_{j\in J}\sum_{p\in P} A_d * Y_{ijpd},\forall d\in D_{work} \quad (2)$$

$$2*\sum_{j\in J}\sum_{p\in P} R_{ijpd}\le\sum_{j\in J}\sum_{p\in P} Y_{ijpd}+1,\forall d\in D_{work},\forall i\in Pt \quad (3)$$

Equations (4) and (5) mean that each regular employee and irregular employee cannot exceed coming to work five days a week due to the 52-h workweek policy. Equations (6) and (7) ensure that all employees must work between 40 and 52 h a week due to the 52-h workweek policy:

$$\sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} X_{ijpd}\le 5,\ \forall i\in I,\ \forall n\in N \quad (4)$$

$$\sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} Y_{ijpd}\le 5,\ \forall i\in Pt,\forall n\in N \quad (5)$$

$$\sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} Parthours_{id}\times Y_{ijpd}\ge 40,\forall i\in Pt, \forall n\in N\ \sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} Parthours_{id}\times Y_{ijpd}\le 52,\forall i\in Pt,\ \forall n\in N \quad (6)$$

$$\begin{gathered}\sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} hours_{id}\times X_{ijpd}+\sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} Overhours_{id}\times O_{ijpd}\ge 40,\\ \forall i\in I,\ \forall n\in N\\ \sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} hours_{id}\times X_{ijpd}+\sum_{j\in J}\sum_{p\in P}\sum_{d\in W_n} Overhours_{id}\times O_{ijpd}\le 52,\\ \forall i\in I,\ \forall n\in N\end{gathered} \quad (7)$$

Equations (8) and (9) determine the allocation of the employee to the workplace and job. Each employee should be assigned to a workplace to perform just only one job. Equation (10) shows that all employees have a day off on Sunday. Equation (11) indicates that the number of employees who come to work is more than the minimum number of employees that a company needs a day:

$$\sum_{j\in J}\sum_{p\in P} X_{ijpd}\le 1,\forall i\in I,\forall d\in D_{work} \quad (8)$$

$$\sum_{j\in J}\sum_{p\in P} Y_{ijpd}\le 1,\forall i\in Pt,\forall d\in D_{work} \quad (9)$$

$$\sum_{i\in I}\sum_{p\in P}\sum_{j\in J} X_{ijpd}+\sum_{i\in Pt}\sum_{p\in P}\sum_{j\in J} Y_{ijpd}+\sum_{i\in I}\sum_{p\in P}\sum_{j\in J} O_{ijpd}=0,\forall d\in D_{sun} \quad (10)$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{p\in P} X_{ijpd}+\sum_{i\in Pt}\sum_{j\in J}\sum_{p\in P} R_{ijpd}\ge Min_d,\forall d\in D_{work} \quad (11)$$

Equations (12)~(14) determine the allocation for the workplace on the first floor and second floor. Equation (12) means that the necessary number of workers, including regular and irregular workers, is more than 15 on each floor at least per day. Equation (13) is about the assignment of a manager for supervision and one manager should work on each floor. Equation (14) means two workers doing Job 2 must be on one of two floors at least:

$$\sum_{i\in I}\sum_{j\in J} X_{ijpd}+\sum_{i\in Pt}\sum_{j\in J} R_{ijpd}\ge 15,\ \forall p\in \mathrm{F},\forall d\in D_{work} \quad (12)$$

$$\sum_{i\in M}\sum_{j\in J} X_{ijpd}\ge 1,\forall d\in D_{work},\forall p\in F \quad (13)$$

$$\sum_{i \in I} \sum_{p \in F} X_{i2pd} = 2, \forall d \ \in D_{work} \tag{14}$$

Equations (15) and (16) determine the allocation to open storage. Equation (15) represents that more than two employees are needed for open storage. Equation (16) means that open storage does not need managers:

$$\sum_{i \in Ep} X_{i13d} + \sum_{i \in Pt} R_{i13d} \geq 2, \forall d \ \in D_{work} \tag{15}$$

$$\sum_{i \in M} \sum_{j \in J} X_{ij3d} = 0, \forall d \ \in D_{work} \tag{16}$$

Equations (17)~(19) are about the allocation to the office. Equation (17) shows that more than one manager should be assigned to the office. Equation (18) means that any other regular employees, besides managers, cannot work in the office. Equation (19) indicates that when managers are assigned to Job 2, they cannot work in the office and should work on one of the first and second floors at least:

$$\sum_{i \in M} \sum_{j \in J} X_{ij4d} \geq 1, \forall d \ \in D_{work} \tag{17}$$

$$\sum_{i \in Ep} \sum_{j \in J} X_{ij4d} = 0, \forall d \ \in D_{work} \tag{18}$$

$$\sum_{i \in I} X_{i24d} = 0, \forall d \ \in D_{work} \tag{19}$$

Equations (20) and (21) are related to the allocation of irregular employees. Equation (20) means that irregular employees cannot perform Job 2. Equation (21) shows that irregular employees also cannot work in the office. Equation (22) represents how many managers must work during the daytime:

$$\sum_{i \in Pt} \sum_{p \in F} R_{i2pd} = 0, \forall d \ \in D_{work} \tag{20}$$

$$\sum_{i \in Pt} \sum_{j \in J} R_{ij4d} = 0, \forall d \ \in D_{work} \tag{21}$$

$$\sum_{i \in M} \sum_{j \in J} \sum_{p \in P} X_{ijpd} = \sum_{i \in M} \sum_{j \in J} X_{ij1d} + X_{ij2d} + X_{ij4d}, \forall d \ \in D_{work} \tag{22}$$

3.3.2. Constraints for Staff Scheduling during Nighttime

Equations (23)~(32) are to determine the allocation of overtime work. Overtime work can be performed by only regular employees according to the rules of this company. In addition, only three types of first floor, second floor, and open storage are considered for the allocation. Equation (23) decides whether employees can work at nighttime or not. It is determined by the condition that only employees who perform daytime work can perform overtime work. Equation (24) represents that employees can work less than three times a week at night, owing to the 52-h workweek policy:

$$2 * \sum_{j \in J} \sum_{p \in P} O_{ijpd} \leq \ \sum_{j \in J} \sum_{p \in P} X_{ijpd} + 1, \ \forall i \in I, \ \forall d \ \in D_{work} \tag{23}$$

$$\sum_{j \in J} \sum_{p \in P} \sum_{d \in W_n} O_{ijpd} \ \leq 3, \ \forall i \ \in I, \ \forall n \in N \tag{24}$$

Equation (25) is about how many employees are needed for overtime work. Equation (26) refers to the allocation of each employee to jobs at nighttime. Equations (27) and (28) determine the allocation for the first floor and second floor. Equation (27) shows more than eight employees are needed for each floor. Equation (28) means that only one employee is assigned to the first floor or second floor to perform Job 2:

$$\sum_{i \in I} \sum_{j \in J} \sum_{p \in P} O_{ijpd} \ \geq overmin_d, \forall d \in D_{work} \tag{25}$$

$$\sum_{j \in J} \sum_{p \in P} O_{ijpd} \leq 1, \forall i \in I \ , \forall d \ \in D_{work} \tag{26}$$

$$\sum_{i\in I}\sum_{j\in J} O_{ijpd} \geq 8, \forall p \ \in \mathrm{F}, \forall d \ \in D_{work} \quad (27)$$

$$\sum_{i\in I}\sum_{p\in F} O_{i2pd} = 1, \forall d \ \in D_{work} \quad (28)$$

Equations (29) and (30) determine the allocation at open storage. Equation (29) indicates that more than one employee should be assigned to open storage. Equation (30) shows that managers cannot be assigned at open storage. Equation (31) means that more than one manager must work at night after working in the daytime. Equation (32) means that no one is assigned to the office during overtime work:

$$\sum_{i\in Ep} O_{i13d} \geq 1, \forall d \ \in D_{work} \quad (29)$$

$$\sum_{i\in M}\sum_{j\in J} O_{ij3d} = 0, \forall d \ \in D_{work} \quad (30)$$

$$\sum_{i\in M}\sum_{j\in J}\sum_{p\in P} O_{ijpd} \geq 1, \forall d \ \in D_{work} \quad (31)$$

$$\sum_{i\in I}\sum_{j\in J} O_{ij4d} = 0, \forall d \ \in D_{work} \quad (32)$$

4. Solution Process

Linear programming used as a method in this paper can be solved by the simplex method. The simplex method can be utilized to solve linear programming [32]. The simplex method is based on forming the inverse of the basic matrix and updating the inverse [33]. That is, it is the repetition of searching for feasible solutions, calculating the value of the objective function, and comparing the derived value and the optimal value until finding the optimal solution. The process of the simplex is shown in Figure 2. First of all, all equations should be converted into standard equation form after inserting slack variables and create an initial simplex table. After this, find the entering variables. When solving the maximization problem, the variable with the largest absolute value of the coefficient becomes the entering variable. The next thing is to find leaving variable. To achieve this, the ration between entering variable and solution should be calculated. At this time, the variable with the lowest ration value becomes the leaving variable. After deciding on entering variable and leaving variable, the intersection point of the entering variable and leaving variable becomes the pivot element and all values of the row in the simplex table with the pivot element should be divided by the pivot element. The rest of the rows should be updated by using the new pivot row made previously. Lastly, if there is no new leaving variable, iterations terminate. If not, go back to the step of finding the entering variable. Various computer packages based on the simplex method were already developed. A developed mathematical model in the paper is also solved by one of the packages. The package used in the paper is CPLEX, which is the mathematical optimization software package. The version is 20.1.0. The darker parts in Figure 2 are processed by CPLEX.

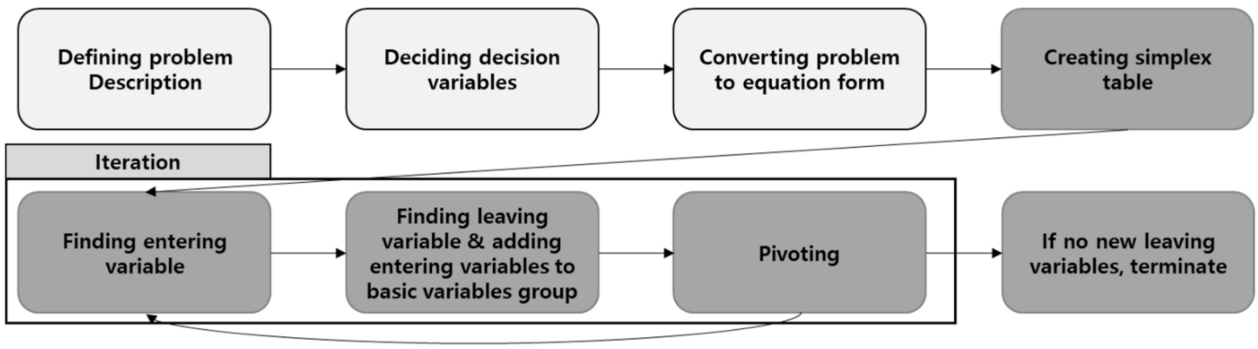

Figure 2. Solution process of the simplex method.

5. Numerical Experiment

5.1. Parameters Setting

The company has 40 regular employees, consisting of 36 normal regular workers and 4 managers. Furthermore, they have 22 irregular employees. The minimum necessary number of employees is at least 45 during the daytime. In addition, the number of workplaces is four spaces, namely the first floor, second floor, open storage, and the office. Other known parameters are set and presented in Table 3, except for known parameters regarding costs. The daily labor cost of each employee for both daytime and overtime is presented in Tables 4 and 5. The known parameters to create an optimal schedule for the numerical experiment are in Table 3.

Table 3. System parameters.

Parameters	Value	Parameters	Value
$hours_{i,d}$	8	min_d	45
$parthours_{pt,d}$	8	$overmin_d$	18
$overhours_{i,d}$	4	A_d	0.8

Table 4. Costs for all employees during daytime (unit: USD/day).

	Manager	Regular Employee	Irregular Employee
Weekday	USD 140	USD 120	USD 110
Weekend	USD 210	USD 180	USD 165

Table 5. Costs for all regular employees during nighttime (unit: USD/day).

	Manager	Regular Employee
Weekday	USD 105	USD 90
Weekend	USD 105	USD 90

The cost for all employees is in Table 4. Each employee is paid daily according to company policy. Regular employees are paid more than irregular employees. Managers are paid about USD 20 more than normal regular employees. The reason for the different levels in paycheck between weekdays and weekends is because of the implementation of a 52-h workweek policy that regards Saturday as an overtime workday. Table 5 represents the paycheck for regular employees at nighttime. The reason the company uses only regular employees at night is because of the rules of the company considered in the paper. They want to allow regular employees to earn money in the middle of a situation where most work is gradually conducted by irregular employees due to the high labor cost of regular employees.

5.2. Result

5.2.1. Before Applying a Mathematical Model

This company did not have a staff schedule before. Due to this, they suffered from inefficient management of human resources. A staff schedule in Figure 3 is made based on the record of employee working patterns. Before the explanation of Figure 3, how to see a staff schedule is explained. In Figure 3, the row number means employees and the column number represents days. The numbers that are the darkest gray in row number stand for managers. The number in each cell indicates the assigned workplace and the cells with the diagonal pattern are Job 2, and without the diagonal pattern are Job 1. When it comes to jobs, Job 1 means normal work and Job 2 is equipment supervisor who takes responsibility for everything regarding equipment. If looking at Figure 3, more employees sometimes came to work than the number of employees a company needs, and fewer employees sometimes came to work than the number of employees a company needs. An example of the former one is Day 3, and the latter is Day 1. Especially, when looking at Day 24, placing enough workforce on the second floor failed. Originally, more than 15 employees should be assigned on each floor during the daytime. However, only 12 employees were assigned that day. This directly shows inefficient human resource management. Moreover, about 46.6 employees came to work on average, which means it was a bigger number than the daily number of employees (45) that a company needs. This causes larger labor costs than when 45 employees come to work, on average.

5.2.2. After Applying a Mathematical Model

Unlike a staff schedule before applying a mathematical model, a derived staff schedule is more efficient. As shown in Figure 4, all constraints regarding work in the daytime are satisfied. For example, 45 employees are scheduled to work if looking at Day 1. In addition, job assignments are met as well. Continuing looking at Day 1, more than 15 employees are assigned on each floor and two of the employees conduct Job 2 as equipment supervisors. Furthermore, more than one manager is assigned on each floor to supervise other regular and irregular employees as well. Moreover, over two of the employees work at open storage and a manager works in an office. That is, the failure of employees' assignments caused by a manager's random employee assignment does not happen. Other days, as well as Day 1 meet all constraints for job assignments. Along with this, the 52-h workweek policy is well applied in the mathematical model as the result shows. There are no employees who come to work for more than five days a week. All employees have a day off on Sunday.

Furthermore, the purpose of the developed mathematical model is to minimize the total labor cost of regular and irregular employees. This means that the result in the numerical experiment is for a company that has a priority of saving the total labor cost. Therefore, if looking at the result in Figure 4, as many irregular employees as possible are scheduled on each workday even though the average percent of irregular employee absence is considered. It is more advantageous for a company to minimize the total labor costs by using as many irregular employees as possible out of 22 irregular employees due to relatively low labor costs. However, it is seen that as many irregular employees as possible are not used. This is because there are rules on conducting jobs for a company and there are jobs that can be conducted by regular employees. A company allocates overtime work by assigning only regular employees to jobs for consideration for regular employees as well. To conduct overtime work, regular employees should work during the daytime. Thus, the result in Figure 4 is derived, even though a company has enough irregular employees that can cover more jobs.

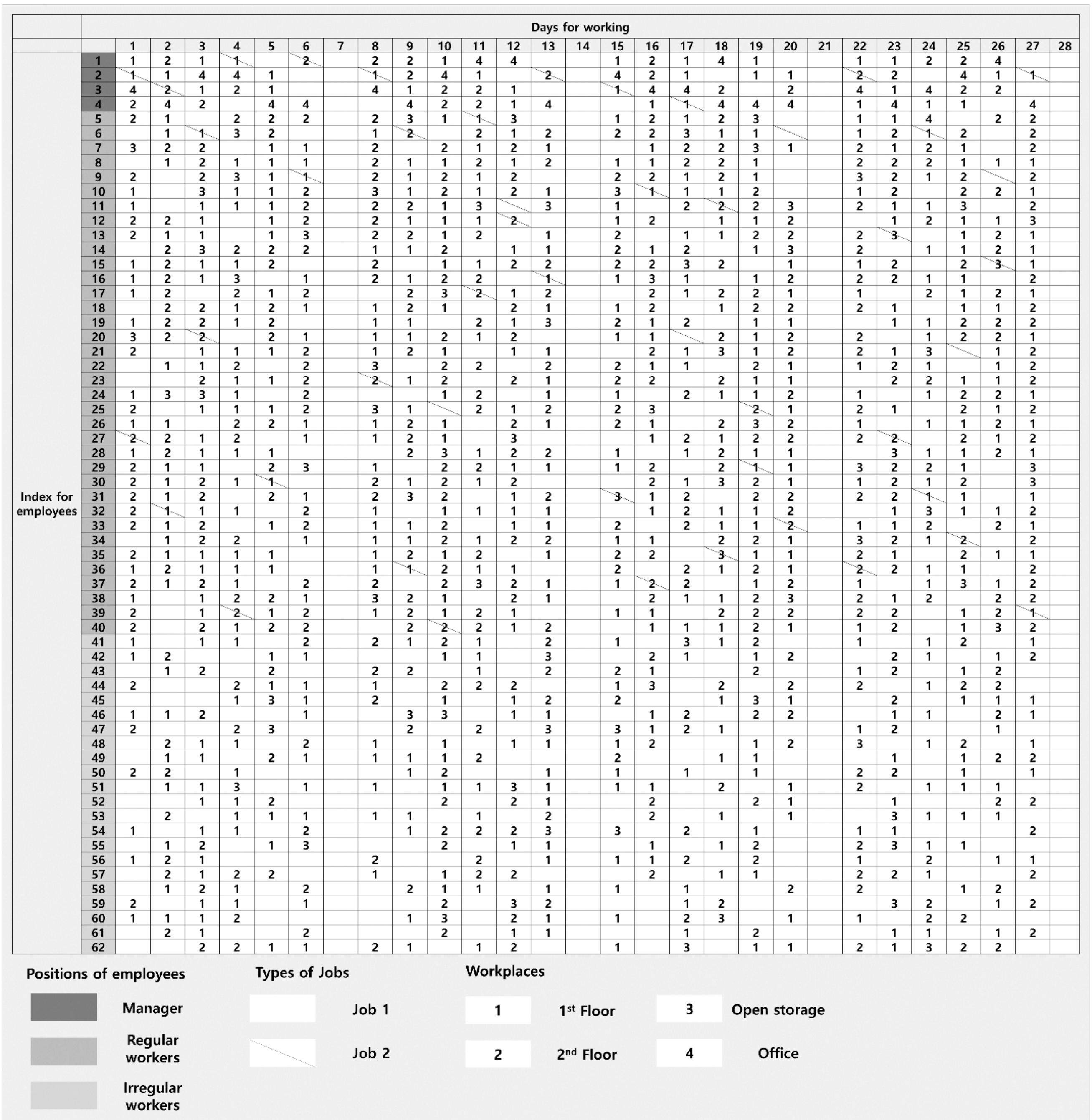

Figure 3. A staff schedule before applying a mathematical model.

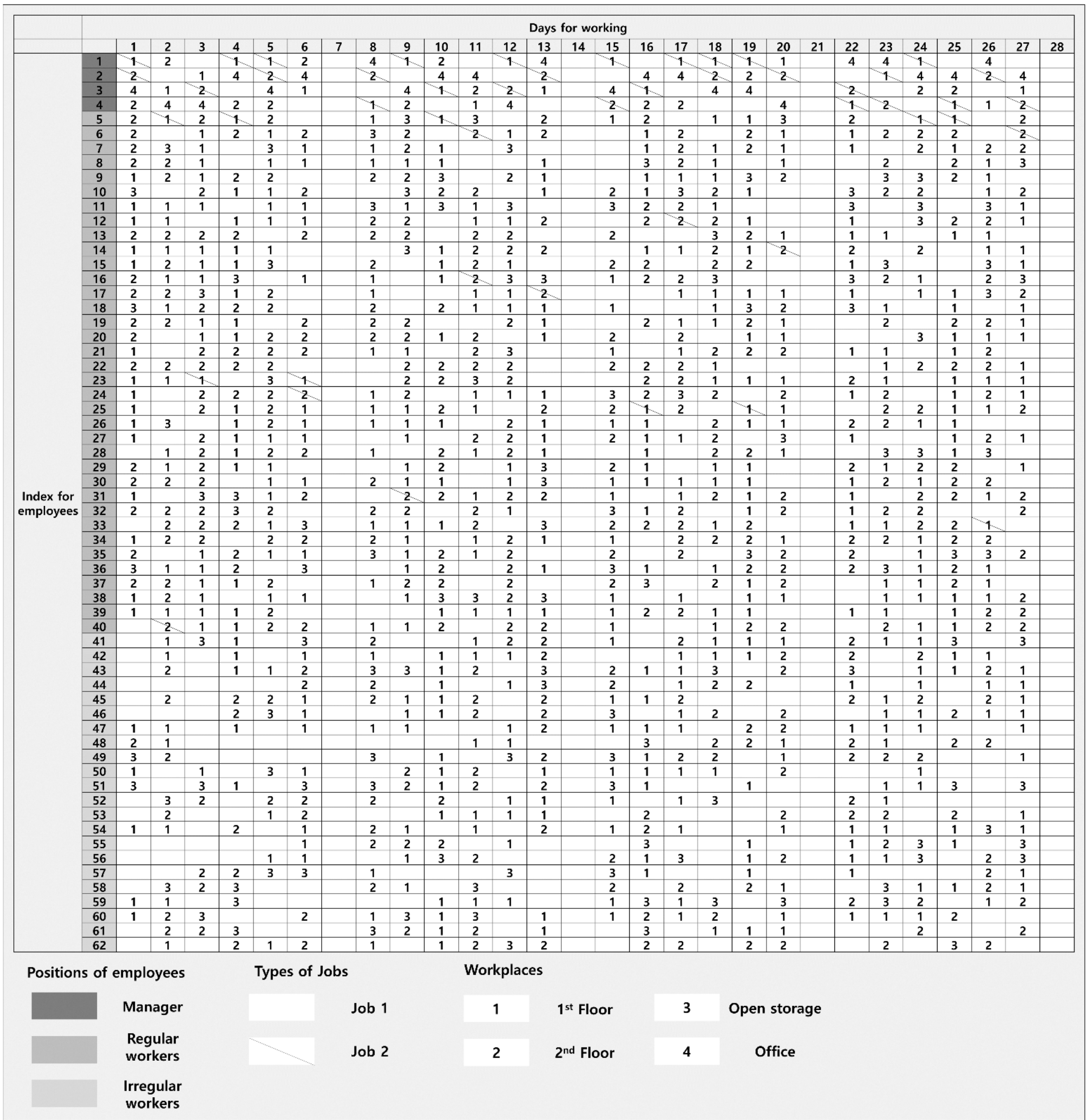

Figure 4. Optimal staff schedule during daytime.

Comparing a staff schedule before and after applying a mathematical model, the following things can be found. First, there is a difference in the number of employees who come to work per day on average. Consequently, about 1.6 employees come to work less than before after applying a mathematical model every day. Second, a developed mathematical model prevents situations where employees come to work more or less than the number of employees a company needs a day. This can aid in the improvement of human resource management. Third, a company can save total labor costs even though the company has the same number of employees as before. It was USD 143,525 before applying a mathematical model and it is USD 138,335 after applying a mathematical model. That is, a company can save a total labor cost of USD 5190. Lastly, the different employee work pattern is found due to consideration of the change in labor policy. Some employees came to work more than 6 days a week before applying a developed model. However, it is constrained by a mathematical model at the moment because a company should follow the change of labor policy, which is each employee should work less than 5 days a week.

The number of days regular employees come to work is constrained after applying a mathematical model due to the change in labor policy and high labor costs. Some regular employees come to work 4 days a week. This could be shown not to allow them to work more. However, it indirectly proved that a company that did not efficiently manage human resources has several employees more than the number they need to have. This can be an opportunity to rethink and optimize the number of employees a company needs to possess.

According to Figure 5, the rules relating to overtime work are also well-considered. First, nobody is assigned to the office. Second, only one manager is assigned to supervise regular employees on one of the two floors. For instance, one manager of four managers is assigned on the first floor to play the role of supervisor during overtime work if looking at Day 1. Third, an employee who performs as equipment supervisor is assigned to one of two floors. Lastly, one employee is also allocated to open storage at least. To sum up, a staff schedule at daytime and nighttime that satisfies constraints is derived considering the total labor cost.

5.3. Evaluation of a Derived Staff Schedule

This paper provides a conservative and deterministic staff schedule by using a mathematical model that considers the average percent of irregular employees' absences, which is an uncertain characteristic. Even though irregular employee absence is stochastic, the reason this paper derives a deterministic staff schedule is that it is impossible to predict if irregular employees come to work or do not come to work perfectly only based on the probability of each irregular employee's absence. That is, even the result derived from the stochastic model cannot guarantee that each irregular employee follows a staff schedule without absences. However, the reason to perform the simulation after deriving a deterministic staff schedule is that it is meaningful in that it can give the result that can help managers respond to the irregular employee's absence. Figure 6 is the result of the simulation. Row numbers from 41 to 62 mean irregular employees and column numbers mean days of work. In addition, O means that irregular employees come to work, and X means that irregular employees do not come to work. The result shows whether each irregular employee follows their schedule when considering each employee's absence percent.

If looking at Table 6 below, the actual percent of each irregular employee's absence is different from the expected percent of each employee's absence. In other words, even though the average percent of an irregular employee's absence is considered as the stochastic characteristic through the simulation, it cannot ensure that managers have a staff schedule that can predict the absences of irregular employees perfectly. Furthermore, as shown in Figure 6, the lacking number of irregular employees can be confirmed. If managers prepare a conservative measure, they will assign more irregular employees on the days when some irregular employees are expected to not come to work. However, preparing additional irregular employees makes extra labor costs for a construction company. Nevertheless, it is more important to finish work by assigning extra irregular employees within due time. Saving labor costs is the next thing to do. Moreover, according to the days of absence shown in Table 6, the number of days when each irregular employee does not come to work can be confirmed. For example, the 44th irregular employee does not come to work 7 days out of 13 days. This irregular employee has an actual percent of absence of 53.8%. It is 23.8% higher than an expected percent of absence of 30%. This type of employee is the main cause to make a company fail to follow a staff schedule and assign enough workforce to jobs. This finding can be an opportunity to help a manager rethink the recruitment of other irregular employees. To sum up, the reason this paper derives a conservative and deterministic staff schedule and performs the simulation about it is that it can contribute to presenting the systematic procedure for irregular employee absence. This procedure could aid managers in preparing precautious measures for a staff schedule while considering the stochastic characteristics of irregular employee absence.

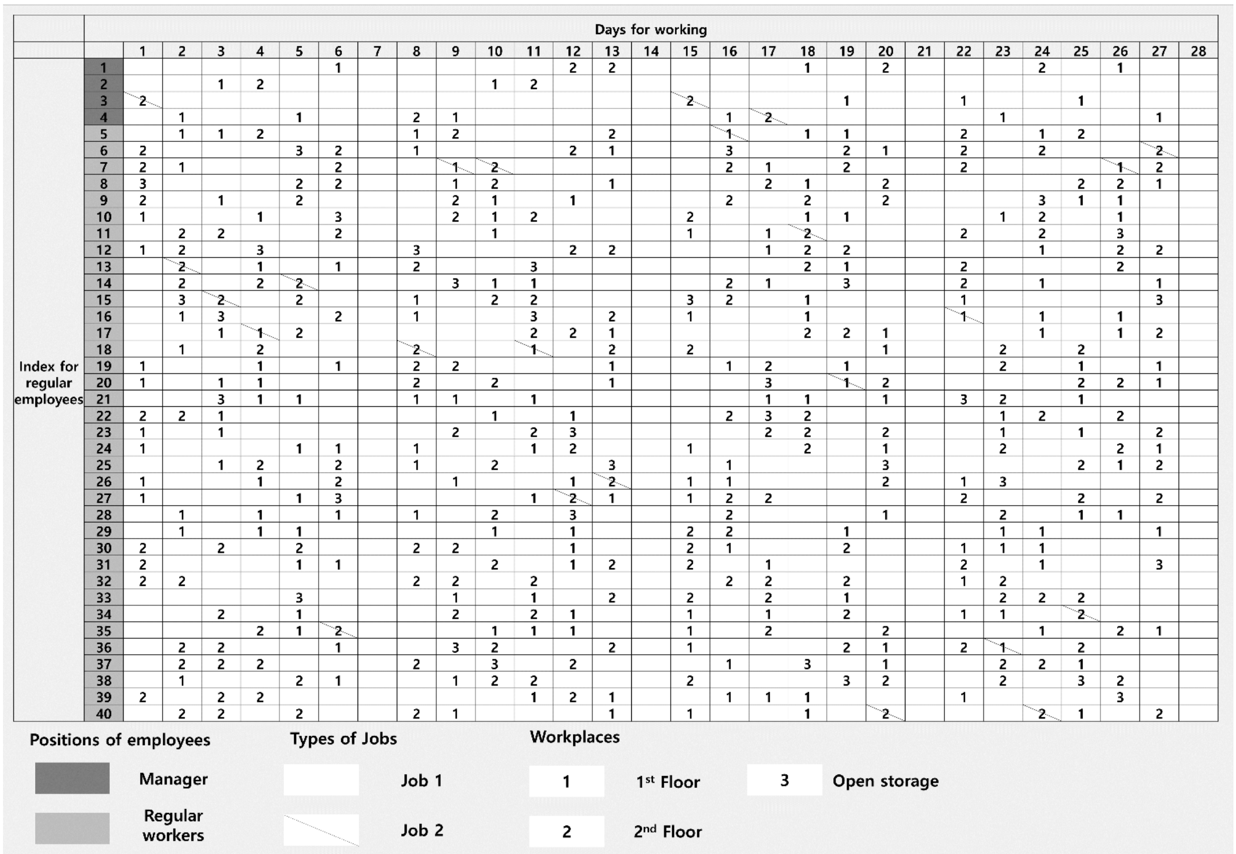

Figure 5. Optimal schedule of regular employees during overtime.

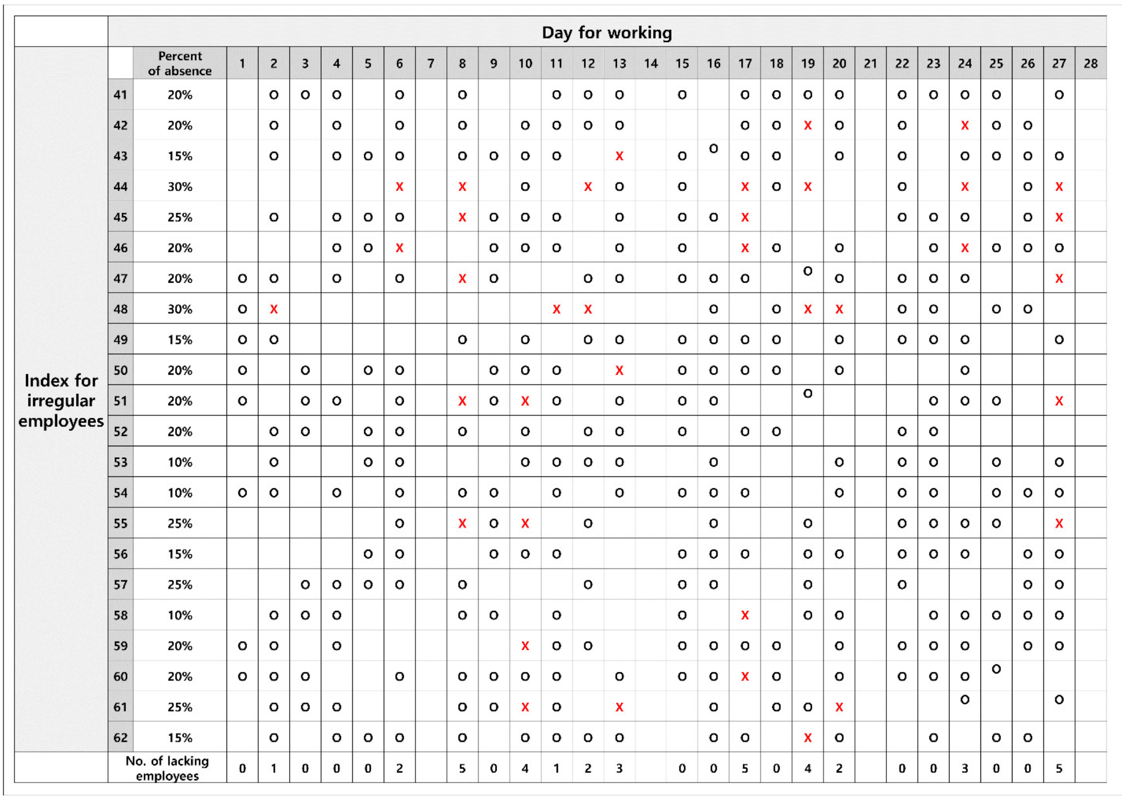

Figure 6. Result of simulation for evaluation of a staff schedule.

Table 6. Information on each irregular employee's work and absence.

Index of Irregular Employees	Expected Percent of Absence	No. of Scheduled Workdays	No. of Absence Days	Days of Absence	Actual Percent of Absence
41	20%	18	0	-	0%
42	20%	16	2	19, 24	12.5%
43	15%	19	1	13	5.3%
44	30%	13	7	6, 8, 12, 17, 19, 24, 27	53.8%
45	25%	17	3	8, 17, 27	17.6%
46	20%	16	3	6, 17, 24	18.6%
47	20%	17	2	8, 27	11.8%
48	30%	12	5	2, 11, 12 19, 20	41.7%
49	15%	15	0	-	0%
50	20%	14	1	13	7.1%
51	20%	16	3	8, 10, 27	18.6%
52	20%	13	0	-	0%
53	10%	13	0	-	0%
54	10%	17	0	-	0%
55	25%	12	3	8, 10, 27	25%
56	15%	15	0	-	0%
57	25%	12	0	-	0%
58	10%	15	1	17	6.7%
59	20%	16	1	11	6.3%
60	20%	18	1	17	5.6%
61	25%	14	3	10, 13, 20	21.4%
62	15%	16	1	19	6.3%

5.4. Sensitivity Analysis

In this mathematical model, the average percent of irregular employee absence is one of the major factors that change the result of the total labor cost and staff schedules. However, the irregular employee absence is unpredictable due to its inherently uncertain nature. Therefore, to observe the change in the total labor cost and staff schedules, the average percent of an irregular employee's absence is examined with a variety of values. The average percent of an irregular employee's absence is set at 100%, 95%, 90%, 85%, 80%, 75%, 70%, 65% and under 60%. By performing sensitivity analysis with these values above, many significant meanings are discovered. As represented in Table 7, total labor costs, the average percent of regular employee attendance, and the average percent of irregular employee attendance differ depending on the average percent of irregular employee's absence. The average percent of regular employee attendance tends to be increased if the average percent of irregular employee absences is decreased. In other words, this is the situation where more regular employees come to work to replace low-paid irregular employees who are absent. This causes a rise in total labor cost because regular employees are paid more than irregular employees. However, 40 regular employees cannot cover all irregular employees who do not come to work when the average percent of irregular employee absence is under 60% as presented in Table 7. Thus, it is necessary that the company either take measures to prevent the average percent of irregular employee absence from becoming too low, or to increase the number of regular employees to derive a staff schedule that can satisfy the necessary workload.

Table 7. Changes in the percent of regular and irregular employees and total cost.

Attendance Rate of Irregular Employees	The Average Percent of Working Regular Employees	The Average Percent of Working Irregular Employees	Total Cost (USD)
100%	63.5%	36.5%	176,860
95%	64.6%	35.4%	177,035
90%	66%	34%	177,205
85%	67.7%	32.3%	177,405
80%	69.1%	30.9%	177,575
75%	70.8%	29.2%	177,770
70%	72.1%	27.9%	177,945
65%	73.8%	26.2%	178,190
Under 60%		Infeasible	

The number of irregular employees expected to come to work, and the number of irregular employees coming to work are different depending on the average percent of irregular employee absence every month in Figure 7. This is because of the influence of the condition that the minimum necessary number of regular employees should come to work to guarantee stability for completing the workload. For this reason, the difference between the number of irregular employees expected to come to work, and the number of irregular employees coming to work is inclined to reduce when the average percent of irregular employee absence is decreased due to an increase in the number of regular employees who cover irregular employees. It implies that gradually decreasing the number of irregular employees while coming up with ideas to encourage them not to be absent is better to keep up stability and reinforce the job efficiency when the necessary number of regular employees is fixed. As a result, given the stability of staff schedules, it is thought that reasonable schedules could be made when the average percent of irregular employee absence is 75%, although the total cost increases a little compared to 80%.

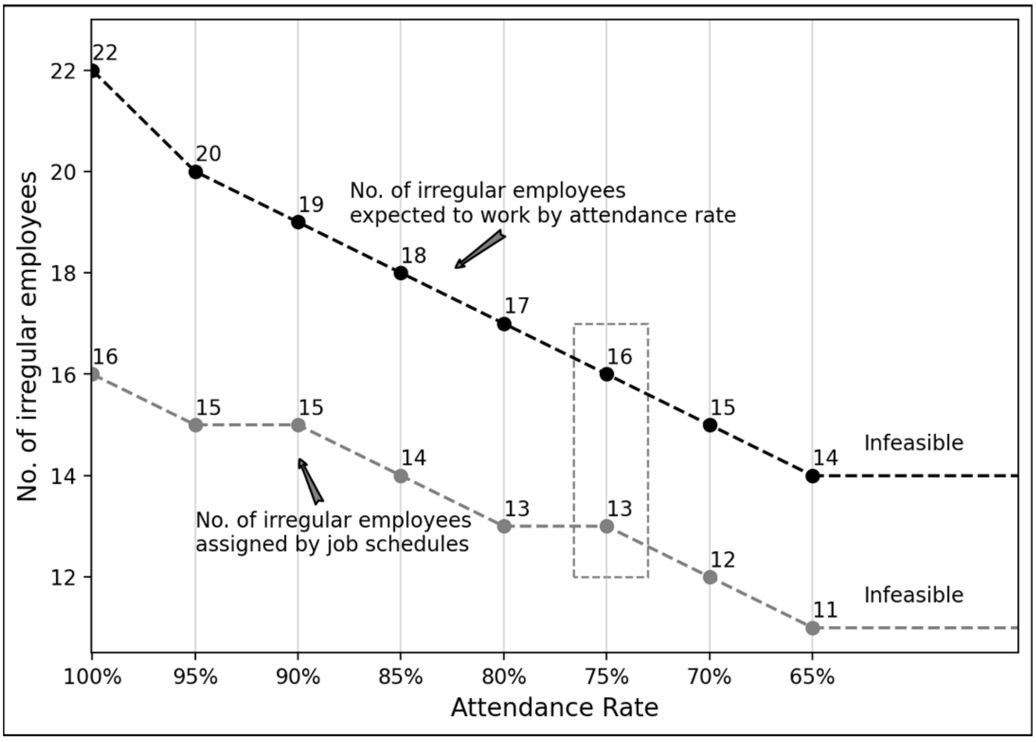

Figure 7. The difference between an expected number and the assigned number of irregular employees depending on attendance rate (the percent of irregular employees' absences).

As mentioned ahead, the average percent of regular employee attendance is increased as the average percent of irregular employee absence is decreased. This results in increasing stability in performing the job. On the other hand, the total labor cost keeps moving up, since the cost of regular employees is normally higher than the cost of irregular employees. In other words, labor costs can be decreased by increasing the number of irregular employees, and the stability of staff schedules can be increased by decreasing the number of irregular employees. Therefore, it is important to make staff schedules considering factors such as labor costs and stability of staff schedules after taking the conditions and situations of a construction company without being biased as one factor. Thus, this research is expected to help a manager with decision-making for a staff schedule by providing various proactive cases depending on the change of the average percent of irregular employee absence through sensitivity analysis in the numerical experiment.

6. Conclusions

6.1. Contributions

This study proposes a staff scheduling strategy to minimize total labor costs considering the actual features of the Korean construction industry, such as an increase in labor costs and the change in labor policy. The contributions of this paper are as follows. First, this paper suggests a mathematical model that can save the total labor cost and aid the management of human resources. As shown in the numerical experiment, a mathematical model decreases the unnecessary number of employees from about 46.6 to 45 a day on average. This can allow a company to have an opportunity to save labor costs and rethink and optimize the number of employees they should have. Second, the practicality to apply the developed mathematical model to other industries is proven. This study considers an actual construction company suffering from the problem of no-show, derived from the situation that the company increases irregular employees to handle workforce shortage due to the rise of labor costs and a new labor policy in Korea. Through the numerical experiment with system parameters derived from human resources, types of jobs, workplaces, and the rules of work of a company, the applicability of the developed mathematical model to a company is proved in practice. Therefore, this paper would help conduct research on staff scheduling for the actual company as one of the basic references. Third, the change in labor policy is considered when developing a mathematical model. The optimal solution for staff scheduling by using this mathematical model is derived in the situation of workforce availability reduction compared to the same number of employees due to the influence of changed labor policy. In other words, this paper could play a role as a guide for staff scheduling that must consider the change of labor policy in the future in Korea. Lastly, this paper assists the manager of a company with decision-making for staff schedules by providing various proactive cases while considering the sudden absence of employees. Despite the difficulty in considering unpredictable employee absence due to the inherently uncertain nature of irregular employees, additional numerical experiments, which are the simulation and sensitivity analysis, are performed in the paper. The result of the simulation predicts what expectedly happens when assuming the application of a deterministic staff schedule in practice. In particular, the predictive information on how many irregular employees would not come to work is given. It is impossible to guarantee that they would follow staff schedules perfectly in the real world. Nevertheless, the reason to perform the simulation is to allow managers to have a systematic procedure to respond to the absence of irregular employees, not to provide a staff schedule that makes all irregular employees follow the staff schedule. Moreover, through this sensitivity analysis with the change of the average percent of absence, this paper observes the influence of irregular employee absence on the change of the value of the objective function and staff schedule. Through the additional numerical experiments, various proactive cases are provided by considering the absence of irregular employees. This can help managers prepare the precautious measures to respond to the stochastic irregular employee's absence. Thus, it is expected to contribute to helping the manager with decision-making for staff schedules.

6.2. Future Research

This paper could be expanded to further staff scheduling research that considers shifts. This paper does not consider shifts due to no shifts in the construction industry in general. However, many studies about staff scheduling consider shifts. Thus, if the developed mathematical model in this paper is improved considering the characteristics of shifts, it is expected that the developed mathematical model could be applied to relatively more and various industries. Furthermore, many objective functions can be considered to gain an optimal solution for staff scheduling. The current objective function is to minimize labor costs. This means that this staff scheduling strategy considers a company more than employees, despite considering the policy called the 52-h workweek policy. However, it seems necessary to create the objective function for a mathematical model that considers employees as well as the company in the future, because employees' satisfaction with job assignments plays a crucial role in an organization's success [34]. Moreover, research on figuring out the factors that influence the sincerity of irregular employees is needed in terms of their welfare. Conducting this research can help make a proper working environment. In conclusion, various factors regarding both company and employees in various ways should be considered to derive a good solution when staff scheduling problems are handled.

Author Contributions: Conceptualization, Y.D.K.; methodology, C.H.P.; software, C.H.P.; validation, Y.D.K., C.H.P.; formal analysis, C.H.P.; investigation, C.H.P.; resources, Y.D.K.; data curation, C.H.P.; writing—original draft preparation, C.H.P.; writing—review and editing, Y.D.K.; visualization, C.H.P.; supervision, Y.D.K.; project administration, Y.D.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Naoum, S.G. Factors influencing labor productivity on construction sites. *Int. J. Product. Perform. Manag.* **2016**, *65*, 401–421. [CrossRef]
2. Choi, D.S.; Le, H.; Lee, Y.D. The relationship between Korean construction industry and GDP in economic development process. *Korean J. Constr. Eng. Manag.* **2013**, *14*, 70–77.
3. Ministry of Employment and Labor. Available online: http://www.moel.go.kr/policy/policyinfo/young/bbsView.do;jsessionid=eCpFT7AfMl1DRaodwQO5ZP7oPDyz3nX1h1E3aRaK8USeBAL84QS8f1LxSw9EZH5W.moel_was_outside_servlet_www1?bbs_seq=20200300901 (accessed on 12 July 2022).
4. Ministry of Employment and Labor. Available online: http://www.moel.go.kr/policy/policydata/view.do?bbs_seq=20191200830 (accessed on 12 July 2022).
5. Ho, H.; Kuvaas, B. Human resource management systems, employee well-being, and firm performance from the mutual gains and critical perspectives: The well-being paradox. *Hum. Resour. Manag.* **2020**, *59*, 235–253. [CrossRef]
6. Kang, S.Y.; Min, S.; Won, D.; Kang, Y.J.; Kim, S. Suggestion of an improved evaluation method of construction companies' industrial accident prevention activities in south korea. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8442. [CrossRef] [PubMed]
7. Kim, S.; Chang, S.; Castro-Lacouture, D. Dynamic modeling for analyzing impacts of skilled labor shortage on construction project management. *J. Manag. Eng.* **2018**, *36*, 04019035. [CrossRef]
8. Korkmaz, S.; Park, D.J. Comparison of safety perception between foreign and local workers in the construction industry in Republic of Korea. *Saf. Health Work* **2018**, *9*, 53–58. [CrossRef]
9. Newsis. Available online: https://mobile.newsis.com/view.html?ar_id=NISX20181211_0000499414#_enliple (accessed on 11 July 2022).
10. Construction & Economy Research Institute of Korea. Available online: http://www.cerik.re.kr/report/issue/detail/2060 (accessed on 12 July 2022).
11. Hamid, A.R.A.; Singh, B.S.B.J.; Mazlan, M.S. The construction labour shortage in Johor Bahru, Malaysia. *Int. J. Eng. Res. Technol.* **2013**, *2*, 508–512.
12. Ward, K.; Grimshaw, D.; Rubery, J.; Beynon, H. Dilemmas in the management of temporary work agency staff. *Hum. Resour. Manag. J.* **2001**, *11*, 3–21. [CrossRef]

13. Cheah, C.Y.; Chew, D.A. Dynamics of strategic management in the Chinese construction industry. *Manag. Decis.* **2005**, *43*, 551–567. [CrossRef]
14. Becker, T. A decomposition heuristic for rotational workforce scheduling. *J. Sched.* **2020**, *23*, 539–554. [CrossRef]
15. Edie, L.C. Traffic delays at toll booths. *J. Oper. Res. Soc.* **1954**, *2*, 107–138. [CrossRef]
16. Van den Bergh, J.; Beliën, J.; De Bruecker, P.; Demeulemeester, E.; De Boeck, L. Personnel scheduling: A literature review. *Eur. J. Oper. Res.* **2013**, *226*, 367–385. [CrossRef]
17. Ganguly, A.; Nandi, S. Using statistical forecasting to optimize staff scheduling in healthcare organizations. *J. Health Manag.* **2016**, *18*, 172–181. [CrossRef]
18. Maenhout, B.; Vanhoucke, M. An integrated nurse staffing and scheduling analysis for longer-term nursing staff allocation problems. *Omega* **2013**, *41*, 485–499. [CrossRef]
19. Ásgeirsson, E.I. Bridging the gap between self-schedules and feasible schedules in staff scheduling. *Ann. Oper. Res.* **2014**, *218*, 51–58. [CrossRef]
20. Memon, A.H.; Zin, R.M. Resource-driven scheduling implementation in Malaysian construction industry. *Int. J. Sustain. Constr. Eng. Technol.* **2010**, *1*, 77–90.
21. Al-Rawi, O.Y.M.; Mukherjee, T. Application of linear programming in optimizing labour scheduling. *J. Math. Financ.* **2019**, *9*, 272–285. [CrossRef]
22. Rocha, M.; Oliveira, J.F.; Carravilla, M.A. Cyclic staff scheduling: Optimization models for some real-life problems. *J. Sched.* **2013**, *16*, 231–242. [CrossRef]
23. Kaya, B.Y.; Dağdeviren, M. A Human Resources Management Application for Hospitality Management in Turkey. *Int. J. Bus. Manag. Stud.* **2018**, *10*, 39–50.
24. Azadeh, A.; Farahani, M.H.; Eivazy, H.; Nazari-Shirkouhi, S.; Asadipour, G. A hybrid meta-heuristic algorithm for optimization of crew scheduling. *Appl. Soft Comput.* **2013**, *13*, 158–164. [CrossRef]
25. Asensio-Cuesta, S.; Diego-Mas, J.A.; Canós-Darós, L.; Andrés-Romano, C. A genetic algorithm for the design of job rotation schedules considering ergonomic and competence criteria. *Int. J. Adv. Manuf. Technol.* **2012**, *60*, 1161–1174. [CrossRef]
26. Ruiz-Torres, A.J.; Ablanedo-Rosas, J.H.; Mukhopadhyay, S.; Paletta, G. Scheduling workers: A multi-criteria model considering their satisfaction. *Comput. Ind. Eng.* **2019**, *128*, 747–754. [CrossRef]
27. Stolletz, R.; Brunner, J.O. Fair optimization of fortnightly physician schedules with flexible shifts. *Eur. J. Oper. Res.* **2012**, *219*, 622–629. [CrossRef]
28. Shuib, A.; Kamarudin, F.I. Solving shift scheduling problem with days-off preference for power station workers using binary integer goal programming model. *Ann. Oper. Res.* **2019**, *272*, 355–372. [CrossRef]
29. Becker, T.; Steenweg, P.M.; Werners, B. Cyclic shift scheduling with on-call duties for emergency medical services. *Health Care Manag. Sci.* **2019**, *22*, 676–690. [CrossRef] [PubMed]
30. Ingels, J.; Maenhout, B. Employee substitutability as a tool to improve the robustness in personnel scheduling. *OR Spectr.* **2017**, *39*, 623–658. [CrossRef]
31. Steenweg, P.M.; Schacht, M.; Werners, B. Evaluating shift patterns considering heterogeneous skills and uncertain workforce availability. *J. Decis. Syst.* **2021**, *30*, 27–49. [CrossRef]
32. Nash, J.C. The (Dantzig) simplex method for linear programming. *Comput. Sci. Eng.* **2000**, *2*, 29–31. [CrossRef]
33. Bartels, R.H.; Golub, G.H. The simplex method of linear programming using LU decomposition. *Commun. ACM* **1969**, *12*, 266–268. [CrossRef]
34. Lorber, M.; Skela Savič, B. Job satisfaction of nurses and identifying factors of job satisfaction in Slovenian Hospitals. *Croat. Med. J.* **2012**, *53*, 263–270. [CrossRef]