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Optimal Planning of Hotel Renovation Projects

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Abstract: This paper presents the development of a novel model for optimizing the planning of hotel renovation projects to maximize hotel revenues during renovation work while minimizing project cost. The model is developed in three main modules: optimization, scheduling, and hotel profit modules. The model integrates an innovative methodology that enables renovation planners to select which hotels to renovate during any fiscal year based on an allocated renovation budget and identify an optimal floor renovation start date, optimal overtime hours usage and number of assigned crews for each renovation activity, and an optimal floor renovation order in each hotel. An application example of three hotels is analyzed to illustrate the use of the model and demonstrate its capabilities. The results of this analysis illustrate the novel contributions of the model and its original capability in generating optimal plans for hotel renovation projects that enable hotel owners to maximize revenues of their hotels during renovation work while minimizing hotel renovation costs.

Keywords: hotel revenues; hotel renovation projects; renovation planning; optimization; Genetic Algorithms (GA)

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1. Introduction

The American Hotels and Lodging Association [1] reported that there were approximately 55,000 hotel properties in the United States in 2021. Many of these hotels are in urgent need of renovation to increase their revenue and minimize their operational expenses [2,3]. These renovations often lead to temporary reduction in revenues due to the partial closure of hotel floors during renovation work [4]. Accordingly, planners of hotel renovation projects need to carefully analyze and optimize renovation decisions in order to maximize the revenues of hotels during renovation work while minimizing their renovation cost. This presents planners of hotel renovation projects with a number of planning challenges, including how to identify (1) which hotels to be renovated during a fiscal year based on allocated renovation budget; (2) optimal floor renovation start date in each hotel; (3) optimal use of overtime hours and number of assigned crews for each renovation activity; and (4) optimal floor renovation order in each hotel, as shown in Figure 1.

First, renovation planners need to prioritize which hotels to renovate during a fiscal year based on the allocated renovation budget. For example, a planner with an allocated renovation budget of $2.3 million for an upcoming fiscal year needs to prioritize which hotels to renovate from a set of five competing hotels that have varying annual revenues and renovation costs. This allocated $2.3 million budget cannot cover the renovation cost of all five hotels in the upcoming fiscal year and therefore the planner needs to select a subset of these five hotels to renovate and another subset to defer to future fiscal years. This decision needs to be optimized to maximize the net profit of all five hotels during the upcoming fiscal year. This can be achieved by carefully analyzing the impact of a number of important factors including hotel daily revenue of each floor, peak seasons, and total renovation cost.

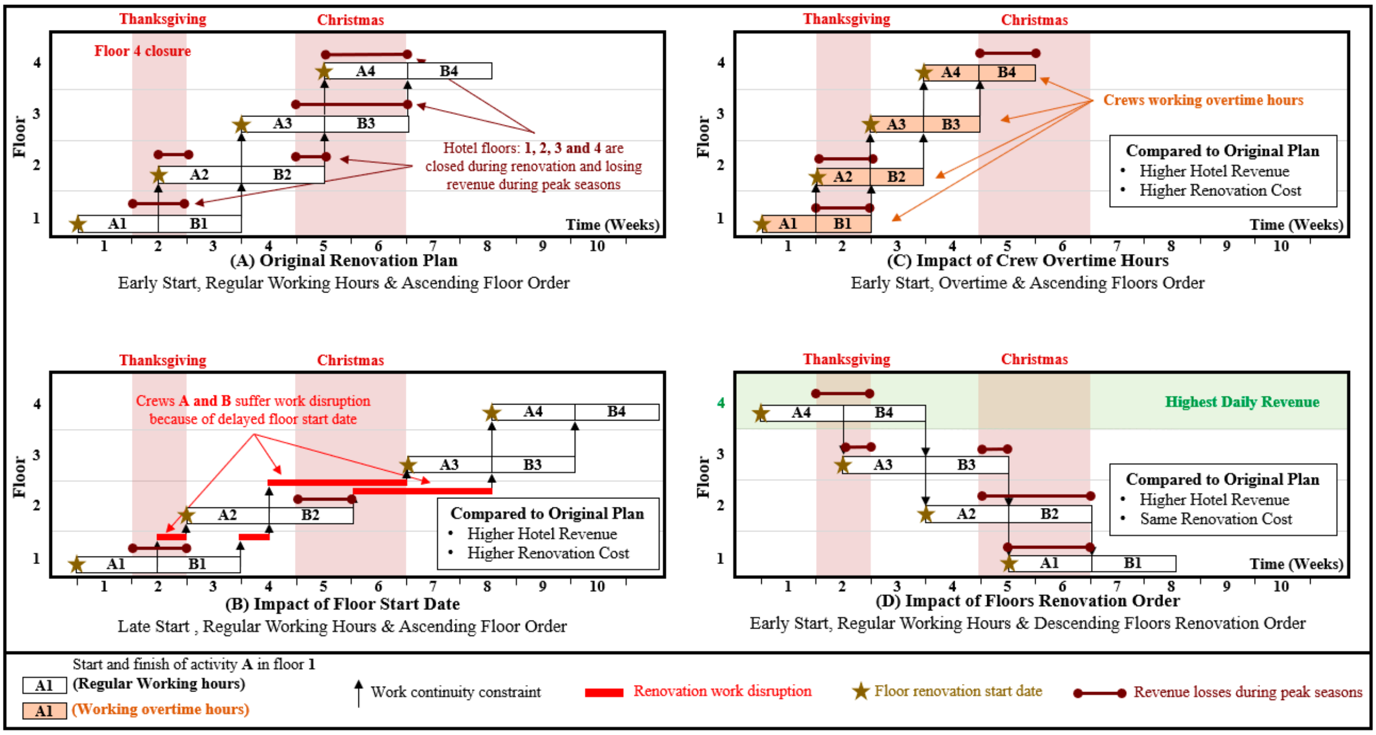


Figure 1. Impact of renovation planning decisions on hotel revenue and cost.

Second, planners need to analyze and optimize the impact of floor renovation start date decision on total hotel profitability, as shown in Figure 1A,B. For example, a renovation planner may select the earliest start date for each floor as shown in the original plan in Figure 1A. Alternatively, the planner may delay the renovation start date in selected floors to minimize floor closures and hotel revenue losses during high peak seasons, as shown in Figure 1B. These two renovation plan examples in Figure 1 illustrate that renovation plan (B) provides higher hotel revenues than those of original plan (A), however it requires higher renovation cost due to work disruption suffered by the crews assigned to activities A and B that were only allowed to resume their work after the end of high peak seasons, as shown in Figure 1. This highlights the need to carefully consider and optimize the selection of floor renovation start dates to maximize hotel net profit.

Third, planners need to study and optimize the impact of using of overtime hours for each renovation activity on total hotel profitability. For example, the impact of the use of overtime hours decision variable on hotel revenue and renovation cost is demonstrated in Figure 1A,C. A renovation planner may select working regular working hours or adding overtime hours for the renovation crews of activities A and B, as shown in Figure 1A,C, respectively. In this example, utilizing overtime hours provides higher hotel revenues than working regular working hours only because it minimizes floor closures during peak seasons, (as shown in Figure 1A,C). On the other hand, utilizing overtime hours requires higher renovation cost due to the higher premiums paid for overtime hours. This demonstrates the need to carefully consider and optimize the use of overtime hours for each renovation activity to maximize hotel net profit. It should be noted that a decision on the selection of the number of renovation crews has a similar impact on hotel net profit as the decision on the use of overtime hours.

Fourth, optimizing the planning of hotel renovation projects needs to identify an optimal floor renovation order that maximizes hotel net profit. For example, a renovation planner may select an ascending floor renovation order starting with floor 1, moving to floor 2, then floor 3, and ending with floor 4, as shown in the original renovation plan in Figure 1A. Alternatively, the planner can select a descending floor order starting by renovating floor 4 first, then floor 3, moving to floor 2, and ending by floor 1 to minimize the closures of floors with high daily revenues such as floor 4 during high peak seasons, as shown in Figure 1D. This highlights the need to carefully consider and optimize the decision on the floor renovation order to maximize hotel profitability. The objective of this paper is to develop a novel model for optimizing the planning of hotel renovation projects that enables decision-makers to identify (1) which hotels to be renovated during a fiscal year based on allocated renovation budget (R_h); (2) optimal floor renovation start date in each hotel (S_f^h); (3) use of overtime hours for each renovation activity in each hotel (x_i^h); (4) number of assigned crews (C_i^h) for each renovation activity; and (5) optimal floor renovation order in each hotel (O_f^h) in order to maximize hotels net profit.

The paper is organized in eight main sections that focus on: (1) providing concise review of related studies and models in the body of knowledge, (2) highlighting the research methodology of this study and the development modules of the present model, (3) describing the model optimization module, (4) presenting the development of the scheduling module, (5) describing the model hotel profit module, (6) analyzing an application example to illustrate the use of the model and demonstrate its capabilities, (7) providing a discussion of the model novelty and its contributions, and (8) highlighting the main conclusions, limitations and future research studies of this paper.

2. Literature Review

Available related research studies focused on: (1) investigating the impact of renovation on hotels performance [2–12], (2) improving the planning of renovation work in existing buildings [13–29], and (3) optimizing the planning of repetitive construction projects [30–39].

First, a number of available research studies focused on investigating the impact of renovation on hotels performance. For example, Hassanien and Baum [2] investigated hotel renovation process and highlighted its significant role as a strategic marketing tool for hotel owners based on a questionnaire survey with 62 hotel general managers. Bloom [5] identified the impact of a renovation process on hotel overall customers' satisfaction, revenues, and profitability based on a quantitative analysis of 46 renovated hotels. Ihsan and Alshibani [10] identified 46 factors that affect the operation and maintenance cost of hotel facilities based on personal interviews with selected operation and maintenance/engineering managers of 47 hotels. Turner and Hesford [3] investigated the long-term and short-term impacts of renovation capital expenditure on revenue, profitability, customer satisfaction, and operational expenses of hotel property based on proprietary project, operational and financial data obtained for 305 hotel renovation projects.

Second, other research studies focused on improving the planning of renovation work in existing buildings. For example, Wayne and Irvvig [28] considered the disruptive impact of renovation activities by prioritizing renovation activities based on building occupants' operations. Ho and Fischer [22] developed a 4D geometric clash detection method that automatically checks renovation phasing plans and detects disturbance between both building occupants and construction crews during renovation projects of occupied buildings. Lee [24] developed a model for optimizing renovation schedules for occupied buildings that mitigate the negative impact of renovation on building occupants. Yee et al. [29] developed a model to identify the interaction between building occupants and renovation crews when sharing the same space. Galiotto et al. [20] proposed an integrated renovation process (IRP) that provides decision-makers with quantitative analysis to generate building renovation alternatives that comply with the specified renovation budget. Abdallah et al. [13] developed a model for optimizing the selection of sustainability measures to minimize life-cycle cost of existing buildings by identifying optimal building fixture selection and percentage of renewable energy compared to the total building energy demand. Cho and Kim [17] developed a model for optimizing the renovation scheduling of office buildings by identifying the optimal horizontal and vertical movements of each renovation crew that minimizes project cost.

Third, the last group of related research studies focused on optimizing the planning of repetitive construction projects. Hegazy and Wassef [33] developed a model for optimizing the scheduling of repetitive construction projects that identifies the optimal construction-method indices, number of additional crews, and work interruptions in order to minimize total construction cost. Huang et al. [34] proposed an optimization model for the scheduling of repetitive projects that selects the optimal set of activity modes, start times, and work sequences between repetitive units to minimize the total project cost while complying with a specified deadline. Salama and Moselhi [39] presented a multi-objective optimization model for repetitive scheduling that consider time, cost and work interruptions trade-offs while considering uncertainties associated with crews' productivity rates, quantities and availability of construction crews. Monghasemi and Abdallah [38] developed an optimization model for planning repetitive construction projects that minimize total project cost by identifying optimal units order, crew deployment times and their movement between units.

Despite the significance and contributions of the aforementioned research studies, they all have limitations in optimizing the planning of hotel renovation projects because they are incapable of considering the aforementioned four main renovation planning challenges. To overcome the limitations of existing research studies and address their research gaps, there is a pressing need for a novel model for optimizing the planning of hotel renovation projects that provides the capability of maximizing the revenues of hotels while minimizing their total renovation cost.

3. Methodology

The present model for optimizing the planning of hotel renovation projects integrates a novel and practical methodology that is performed in three main modules: (1) optimization module that searches for and identifies an optimal renovation plan that maximize hotels net profit by maximizing their total revenues while minimizing total renovation cost during planning fiscal years; (2) scheduling module that computes the start and finish dates, and total work disruption for each renovation activity (i) in each floor (f) in all selected hotels ($h = 1$ to H); and (3) hotel profit module that calculates total revenue and renovation cost for each generated renovation plan in the optimization module, as shown in Figure 2. The following sections describe the development and computations of these modules.

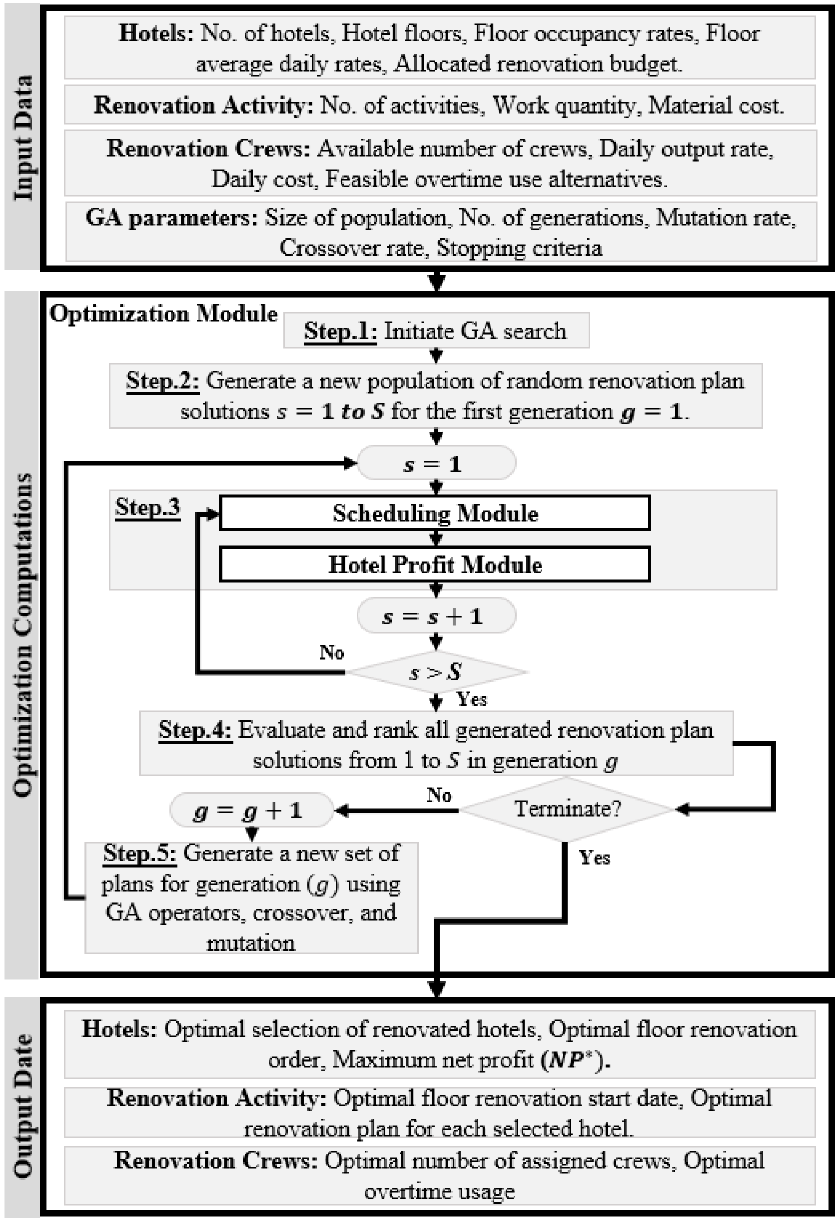


Figure 2. Model development modules.

4. Optimization Module

The objective of this module is to formulate and implement an innovative model for optimizing the planning of hotel renovation projects. The model is designed to maximize hotels' net profit by maximizing their total revenues during renovation work while minimizing their renovation during the planning fiscal year. The optimization module is developed in four main phases that are designed to: (1) identify all relevant decision variables; (2) formulate the optimization objective function; (3) define the model constraints: and (4) execute the computations of the optimization model. The following subsections provide a concise description of these development phases of the optimization module.

4.1. Decision Variables

The purpose of this phase is to identify all possible decision variables that affect revenues of hotels during renovation work and their renovation cost. Accordingly, the identified decision variables in this model are: (1) hotel renovation selection (R_h); (2) floor renovation start date in each hotel (S_f^h); (3) use of overtime hours for each renovation activity in each hotel (x_i^h); (4) number of assigned crews for each activity in each hotel (C_i^h); and (5) floor renovation order for each hotel (O_f^h). It should be noted that the implementation of the model-generated optimal solutions for these five decision variables require collaboration and agreement between hotel owners and contractors during the renovation planning phase. For example, hotel owners and contractors can utilize the developed model during the planning phase to generate an optimal renovation plan that maximizes total hotel revenues while minimizing total project cost. Successful execution of this optimal renovation plan requires collaboration and agreement between hotel owners and contractors to implement the optimal solutions for the aforementioned five decision variables during renovation work.

4.1.1. Hotel Renovation Selection

This decision variable (R_h) represents the selection of renovated hotels from a set of competing hotels during any fiscal year based on a limited allocated renovation budget that cannot cover the total renovation cost of all competing hotels. R_h is modeled using a binary decision variable that can have a value of either 1 or 0, where a value of 1 represents that hotel h was selected to be renovated and a value of 0 represents that hotel h was not selected for renovation.

4.1.2. Floor Renovation Start Date

The second decision variable (S_f^h) represents the selection of a renovation start date for each floor f in each hotel h. This decision variable $\left(S_f^h\right)$ is modeled using a positive integer variable that ranges from a minimum value of zero to a maximum value of (E_f^h) that is specified by the planner for each floor f in each hotel h, as shown in Equation (1).

$$0 \leq S_f^h \leq E_f^h, \quad f \in F_h \;\&\; h \in H \tag{1}$$

where S_f^h is renovation start date of floor f in hotel h in day; E_f^h is planner specified latest renovation start date of floor f in hotel h in day.

4.1.3. Use of Overtime Hours

The third decision variable in this model (x_i^h) represents the selection of overtime hours for each renovation activity i in each hotel h. This decision variable (x_i^h) is modeled using a positive integer number that ranges from zero to the specified maximum number of daily overtime hours (X_i), as shown in Equation (2).

$$0 \leq x_i^h \leq X_i, \quad \forall\, i \in I \;\&\; h \in H \tag{2}$$

where x_i^h is selected daily overtime hours for renovation activity i in hotel h in hour per workday; X_i is planner specified maximum number of daily overtime hours for each renovation activity i in hours per workday.

4.1.4. Number of Assigned Crews

The fourth decision variable in this model represents the number of assigned crews $\left(C_i^h\right)$ for each renovation activity i in each hotel h. This decision variable $\left(C_i^h\right)$ is modeled using a positive integer number that ranges from one to a planner specified maximum number of available crews $\left(A_i^h\right)$ that can be assigned to activity i in each hotel h, as shown in Equation (3). For example, $A_D^3 = 5$ indicates that there is a maximum number of five renovation crews that can be assigned to activity D in the third hotel ($h = 3$), and $C_D^3 = 3$ represents the assignment of three renovation crews for activity D in the third hotel.

$$1 \leq C_i^h \leq A_i^h, \quad \forall\, i \in I \;\&\; h \in H \tag{3}$$

where C_i^h is number of assigned crews to perform renovation activity i in hotel h; A_i^h is the planner-specified maximum number of available crews for activity i in hotel h.

4.1.5. Floor Renovation Order

The last decision variable in this model $\left(O_f^h\right)$ represents the renovation order of each floor f in each hotel h and it is modelled as a unique integer number, as shown in Equation (4). For example, $O_4^2 = 3$ indicates that the renovation order of the fourth floor in a second hotel is planned to be third in the renovation project.

$$1 \leq O_f^h \leq F_h, \forall f \in F_h \,\&\, h \in H \qquad O_k^h \neq O_z^h,\ \forall k \neq z, \qquad k, z \in \{1, \ldots, F\} \tag{4}$$

where O_f^h is renovation order for each floor f in hotel h; F is total number of floors in hotel h.

4.2. Objective Function

The objective function of this model is designed to maximize hotels' net profit (NP) that is represented by the difference between (1) total revenues of all hotels (HR) being consider for renovation during any fiscal year; and (2) total renovation cost (RC) of all hotels selected for renovation during any fiscal year which consists of material cost (MC), crew cost (CC), work disruption cost (PC), and indirect cost (IC), as shown in Equations (5) and (6). These hotel revenues and renovation costs are quantified in the hotel profit module discussed in the next sections.

$$Maximize\ NP = Maximize\ (HR - RC) \tag{5}$$

$$RC = MC + CC + PC + IC \tag{6}$$

where NP is total hotel revenues during a planning fiscal year in \$; HR is total hotel revenues during a planning fiscal year in \$; RC is total renovation cost of all selected hotels in \$; MC is material cost of renovation activities in all selected hotels in \$; CC is crew cost of renovation activities in all selected hotels in \$; PC is work disruption cost of renovation activities in all selected hotels in \$; IC is indirect cost of all selected hotels in \$.

4.3. Planning Constraints

In order to ensure the practicality of the developed model, it is designed to comply with two types of constraints: (i) allocated renovation budget constraint, and (ii) hotel completion deadline constraint. First, the renovation budget constraint is integrated in the model to ensure that the total renovation cost of all selected hotels for renovation does not exceed the allocated renovation budget, as shown in Equation (7). Second, the hotel completion deadline constraint is integrated in the model to ensure that the renovation work of all selected hotels is completed before a planner specified completion deadline (DL_h) for each hotel h, as shown in Equation (8).

$$RC \leq \text{ allocated renovation budget} \tag{7}$$

$$FD_h \leq DL_h \tag{8}$$

where FD_h is finish date of renovation work in hotel h; DL_h is planner specified completion deadline for hotel h.

4.4. Optimization Computations

The optimization computations are executed using Genetic Algorithms (GAs) due to its capability of (a) dealing with the non-linear objective function and constraints of the model, and (b) identifying near optimal solutions for this class of problem in a reasonable computational time [13,30,31,39]. The optimization computations are accomplished in five main steps that are designed to: (1) read all required input data provided by the renovation planner including hotel, renovation activity and crew data; (2) generate a new population of random renovation plan solutions $s = 1$ to S for the first generation $g = 1$, where each solution s represents a random selection for each the aforementioned model decision variables; (3) compute the renovation schedule, total net profit for each solution $s = 1$ to S in generation g using the scheduling and hotel profit modules; (4) evaluate and rank all generated renovation plan solutions from 1 to S in generation g; (5) perform GA operations of selection, crossover and mutation to generate a new set of solutions for the next generation $g = g + 1$ and then repeat the evaluation of their fitness in the next iteration starting with step 3, as shown in Figure 2. This iterative process is terminated when the specified GA stopping criteria are satisfied and the model generates its output data.

5. Scheduling Module

The goal of this module is to develop a practical schedule for all renovation activities (i = 1 to I) in each floor f in each selected hotel h. This developed schedule is designed to comply with all relevant scheduling constraints including job logic, precedence relationship, maximum number of available renovation crews, and specified completion deadline for each hotel h. The scheduling computations in this module are designed to generate a practical renovation schedule that provides planners with the flexibility to: (1) utilize single or multiple renovation crews for each activity in each hotel, (2) schedule multiple concurrent hotel renovation projects with varying completion deadlines, (3) consider all types of repetitive renovation activities that may have identical and/or varying durations in different floors in each hotel, (4) consider single and/or multiple predecessors (P_i) for each renovation activity in the project, and (5) consider varying renovation order for each floor f in each hotel h using the earlier described floor renovation order decision variable.

The computations of this module require the following hotel, renovation activities and crews input data: total number of selected hotels (H), total number of floors in each hotel (F_h), peak (PK_h) and off-peak (OP_h) seasons of each hotel h, completion deadline for each hotel (DL_h), total number of renovation activities I in each hotel h, quantity of work for each activity in each floor in each hotel $\left(Q^h_{i,f}\right)$, list of predecessors for each renovation activity (P_i), feasible overtime hour use alternatives for each renovation activity (X_i), daily output rate of each feasible overtime alternative for each renovation activity (OR_{x_i}), and earliest crew deployment date for each renovation activity (CD_i), as shown in Figure 2. The scheduling module utilizes this input data to perform its computations in four steps:

I. Calculate work duration $(D^h_{i,f})$ of activity i in each floor f in each hotel h based on its quantity of work $(Q^h_{i,f})$, number of assigned crews (C^h_i), and daily output rate of the selected overtime hour use alternative (OR_{x_i}), as shown in Equation (9).

$$D^h_{i,f} = \frac{Q^h_{i,f}}{C^h_i * OR_{x_i}} \quad \forall\, i \in I\ \&f \in F\ \&\ h \in H \tag{9}$$

where $D^h_{i,f}$ is duration of activity i in floor f in hotel h in days; $Q^h_{i,f}$ is quantity of work of activity i in floor f in hotel h in unit of measurement; OR_{x_i} is daily output rate of selected overtime alternative x_i assigned to activity i in unit of measurement per workday.

II. Calculate the start date $(SD^h_{i,f})$ of each renovation activity i in floor f of hotel h that satisfies job logic and precedence relationship constraints. For activities with no predecessors, $SD^h_{i,f}$ is identified as the latest of the crew deployment date (CD_i) and the floor renovation start date (S^h_f), as shown in Equation (10a). For activities with one or more predecessors, $SD^h_{i,f}$ is identified as the latest of the crew deployment date (CD_i) and the latest activity start date which is dependent on the finish dates of its predecessors and their specified lag times, as shown in Equation (10b).

$$SD^h_{i,f} = max(CD_i, S^h_f) \quad \text{for activities with no predecessor} \quad \forall\, i \in I \;\&\; p_i = 0 \tag{10a}$$

$$SD^h_{i,f} = max(CD_i, max^{P_i}_{p_i=1}[FD^h_{pi,f} + lag_{p_i}]) \quad \forall\, i \in I \;\&\; f \in F \;\&\; p_i \in P_i \tag{10b}$$

where CD_i is earliest possible crew deployment date of activity i in day; $SD^h_{i,f}$ is start date of activity i in floor f of hotel h; $FD^h_{pi,f}$ is finish date of predecessor activity p_i in floor f of hotel h; Lag_{pi} is specified lag time between finish date of predecessor p_i and start date of activity i.

III. Calculate the finish date ($FD^h_{i,f}$) of each renovation activity i in each floor f of hotel h based on the activity start date and duration, as shown in Equation (11):

$$FD^h_{i,f} = SD^h_{i,f} + D^h_{i,f} \quad \forall\, i \in I \;\& f \in F \;\&\; h \in H \tag{11}$$

where $FD^h_{i,f}$ is finish date of activity i in floor f of hotel h; $SD^h_{i,f}$ is start date of activity i in floor f of hotel h; $D^h_{i,f}$ is duration of activity i in floor f in hotel h in days.

IV. Compute the crew work disruption time (W^h_i) of each renovation activity i in hotel h based on its start date in successor floor with renovation order of (O^h_{f+1}) and its finish date in floor (O^h_f), using Equation (12):

$$W^h_i = SD_{i,O^h_f+1} - FD_{i,O^h_f} \quad \forall\, i \in I \;\&\; \forall\, O_f \in F-1 \tag{12}$$

where W^h_i is crew work disruption time of activity i in hotel h in day; SD_{i,O^h_f+1} is start date of activity i in successor floor with renovation order $O^h_f + 1$ in hotel h; FD_{i,O^h_f} is finish date of activity i in floor with renovation order O^h_f in hotel h.

6. Hotel Profit Module

The objective of this module is to quantify and calculate the net profit (NP) of each generated renovation plan solution. This net profit (NP) is calculated as the difference between (1) total revenues of all hotels (HR) being considered for renovation during any fiscal year; and (2) total renovation cost (RC) of all hotels selected for renovation during any fiscal year which consists of material cost (MC), crew cost (CC), work disruption cost (PC), and indirect cost (IC), as shown in Equation (5). The hotel net profit (NP) is calculated in this module using the following five steps:

I. Calculate total hotel revenues (HR) based on (i) daily occupancy rates of each floor f in each hotel h before renovation ($BO^h_{f,n}$) and after renovation ($AO^h_{f,n}$), and (ii) average daily rates of each floor f in each hotel h before renovation ($BDR^h_{f,n}$) and after renovation ($ADR^h_{f,n}$), as shown in Equations (13)–(18). It should be noted that the model provides planners with the flexibility to specify the need to vacate the upper and/or lower floors of each floor being renovated to mitigate renovation work noise and its negative impact on hotel residence. In these cases, the model is designed to calculate the associated noise mitigation cost due to the additional floor closures and consider its impact on total hotel revenues, as shown in Equations (15)–(17).

$$BR = \begin{cases} \sum\limits_{h=1}^{H} \sum\limits_{f=1}^{F} \sum\limits_{n=1}^{N=365} BO^h_{f,n} * BDR^h_{f,n} & if\; n < S^h_f \\ zero & otherwise \end{cases} \tag{13}$$

$$AR = \begin{cases} \sum_{h=1}^{H} \sum_{f=1}^{F} \sum_{n=1}^{N=365} AO_{f,n}^{h} * ADR_{f,n}^{h} & if\ n > FD_{f}^{h} \\ zero & otherwise \end{cases} \tag{14}$$

$$NC_L = \begin{cases} \sum_{h=1}^{H} \sum_{f=2}^{F} \sum_{n=1}^{N=365} BO_{f,n}^{h} * BDR_{f,n}^{h} & if\ S_{f-1}^{h} \leq n \leq FD_{f-1}^{h}\ and\ NM_{L}^{h} = 1 \\ zero & otherwise \end{cases} \tag{15}$$

$$NC_U = \begin{cases} \sum_{h=1}^{H} \sum_{f=1}^{F-1} \sum_{n=1}^{N=365} BO_{f,n}^{h} * BDR_{f,n}^{h} & if\ S_{f+1}^{h} \leq n \leq FD_{f+1}^{h}\ and\ NM_{U}^{h} = 1 \\ zero & otherwise \end{cases} \tag{16}$$

$$NC = NC_L + NC_U \tag{17}$$

$$HR = BR + AR - NC \tag{18}$$

where $BO_{f,n}^{h}$ is daily occupancy rate of floor f in hotel h on calendar day n before renovation in %; $BDR_{f,n}^{h}$ is average daily rate of floor f in hotel h on calendar day n before renovation in \$/day; $AO_{f,n}^{h}$ is daily occupancy rate of floor f in hotel h on calendar day n after renovation in %; $ADR_{f,n}^{h}$ is average daily rate of floor f in hotel h on calendar day n after renovation in \$/day; FD_{f}^{h} is finish date of renovation work in floor f in hotel h; BR is total revenue gains of all hotels before renovation in \$; AR is total revenue gains of all hotels after renovation in \$; NC_L is total noise mitigation cost of all hotels resulting from closures of lower floors in \$; NC_U is total noise mitigation cost of all hotels resulting from closures of upper floors in \$; NC is total noise mitigation cost of all hotels resulting from closures of upper and/or lower floors in \$.

II. Calculate total material cost (MC) of all activities ($i = 1\ to\ I$) in each floor f of hotel h based on material cost rate of each renovation activity, and its quantity of work in floor f of hotel h, as shown in Equation (19):

$$MC = \sum_{h=1}^{H} \sum_{f=1}^{F} \sum_{i=1}^{I} M_i * Q_{i,f}^{h} \tag{19}$$

where M_i is material cost rate of activity i in \$ per unit of measurement; $Q_{i,f}^{h}$ is quantity of work of activity i in floor f of hotel h in units of measurement.

III. Calculate total crew cost (CC) that account for labor and equipment costs of all activities ($i = 1\ to\ I$) in each floor f of hotel h based on the number of assigned crews to perform activity (i), their daily crew cost rates, and duration of activity i in floor f of hotel h, using Equation (20):

$$CC = \sum_{h=1}^{H} \sum_{f=1}^{F} \sum_{i=1}^{I} C_{i}^{h} * DC_{x_i}^{h} * D_{i,f}^{h} \tag{20}$$

where $DC_{x_i}^{h}$ is daily crew cost rate of selected overtime alternative x_i for renovating activity i in hotel h in \$ per day.

IV. Calculate total work disruption cost (PC) of all renovation activities ($i = 1\ to\ I$) incurred when a crew has to wait before resuming work in its next assigned floor. A work disruption is often encountered when the next assigned floor is unavailable for renovation due to (1) planner-specified delay in the renovation start date of selected floors to minimize their closures and hotel revenue losses during high peak seasons, as shown in Figure 1B; and/or (2) ongoing work of predecessor renovation activities. This cost is calculated based on the number of work disruption periods (W_i^h) for each activity i and its associated daily work disruption cost (DPC_i) specified by the planner, using Equation (21):

$$PC = \sum_{i=1}^{I} \sum_{h=1}^{H} W_i^h * DPC_i \tag{21}$$

where W_i^h is work disruption of activity i in hotel h in days; DPC_i is daily work disruption cost of activity i in \$/day.

V. Calculate total indirect cost (IC) for each selected hotel (h) based on project duration (PD_h) and daily indirect cost rate (INR_h) that accounts for all time-dependent costs such as site supervision, site utilities, and office overhead, as shown in Equation (22).

$$IC = \sum_{h=1}^{H} PD_h * INR_h \qquad \forall\, h \in H \tag{22}$$

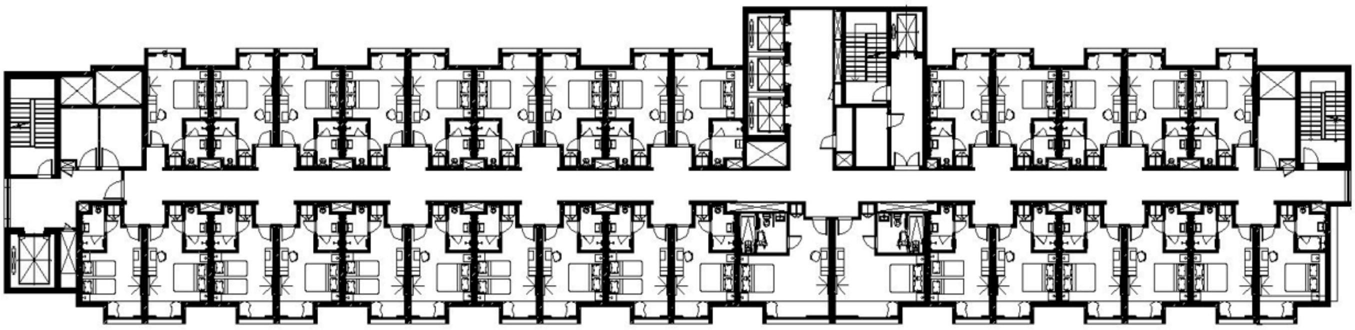
where PD_h is duration of renovation work in hotel h in days; INR_h is daily indirect cost rate for hotel h in \$/day.

7. Application Example

A hypothetical application example was analyzed to illustrate the use of the developed model and demonstrate its capabilities in optimizing the planning of renovation work in three hotels. The scope of work in this example focused on the renovation of 10 floors with 32 rooms per floor in the first hotel ($h = 1$), 15 floors with 24 rooms per floor in the second hotel ($h = 2$), and 12 floors with 28 rooms per floor in the third hotel ($h = 3$), as shown in Figure 3. In this example, a renovation planner needs to make decisions on (1) which hotels to select for renovation for the upcoming fiscal year from the three competing alternatives based on an allocated renovation budget of $12.5 M; (2) floor renovation start date in each hotel; (3) use of overtime hours and number of assigned crews for each renovation activity; and (4) floor renovation order in each hotel.

The planned renovation work in the three hotels can be represented by 16 activities that are grouped into six main categories: demolition and removal, plumbing, electricity, painting, flooring, and furniture as shown in Table 1. The precedence relationships among all activities are specified to be finish-to-start with no lag time. Table 1 summarizes the required scope of work for each of the 16 activities in this example including its predecessors (P_i), unit of measurement, quantity of work per floor in each hotel ($Q_{i,f}^h$), material cost per unit of measurement (M_i) and maximum number of available crews for each hotel (A_i^h). Table 2 summarizes all feasible overtime alternatives for each of the 16 activities including number of overtime hours per workday, crews daily output rates (OR_{x_i}), their daily cost rates (C_{x_i}). Table 3 summarizes daily work disruption cost (DPC_i^h) for each renovation activity i. The expected revenue data of the three hotels are summarized in Tables 4–7 that specify daily occupancy rates of each floor f in each hotel h before renovation ($BO_{f,n}^h$) and after renovation ($AO_{f,n}^h$), average daily rates of each floor f in each hotel h before renovation ($BDR_{f,n}^h$) and after renovation ($ADR_{f,n}^h$). The daily indirect cost rate and the completion deadline (DL_h) for all the three hotels were specified to be $830/day and 20 December 2023, respectively. In this application example, the three hotels do not require noise mitigation measures that specify closures of upper and/or lower floors during renovation work (NM_L^h *and* $NM_U^h = 0$).

In this application example, the developed model was used to search for and identify an optimal renovation plan for all hotels that maximize their net profits (NP) in the upcoming fiscal year. The optimization computations were executed using five main steps (see Figure 2) that were designed to (1) read all required input data provided by the renovation planner including hotel, renovation activity and crew data, as shown in Figure 2 and Tables 1–7; (2) generate a new population consisting of 250 random renovation plan solutions for the first generation $g = 1$, where each solution s represents a random selection for each the aforementioned model decision variables; (3) compute the renovation schedule, total net profit for each solution $s = 1\ to\ 250$ in generation g using the scheduling and hotel profit modules; (4) evaluate and rank all generated renovation plan solutions from 1 to 250 in generation g; (5) perform GA operations of selection, crossover and mutation to generate a new set of solutions for the next generation $g = g + 1$ and then repeat the evaluation of their fitness in the next iteration starting with step 3, as shown in Figure 2. This iterative process was set to terminate when the average relative change in the fitness function value over 32,000 trials (generations) is less than 0.001. The computational time for this application example was approximately 40 min using a personal computer with 11th Gen Intel Core i7 Processor and 12GM RAM.



Hotel One

Hotel Two

Hotel Three

Figure 3. Hotel floor layouts.

Table 1. Renovation activity data.

Activity Number (i)	Activity Description	Predecessor Activities (P_i)	Unit of Measurement	Quantity of Work per Floor ($Q^h_{i,f}$)			Material Cost (M_i) ($)	Maximum Available Crews for Each Hotel (A^h_i)
				Hotel 1	Hotel 2	Hotel 3		
	Demolition and Removal							
1	Carpet, bonded, including surface scraping	-	S.F. *	2080	1560	1820	0	9
2	Bathtub and showerhead	1	Each **	32	24	28	0	10
3	Sink, single compartment, and faucets	2	Each	32	24	28	0	9
4	Water closets (Toilet)	3	Each	32	24	28	0	9
5	Tile, ceramic, thin set	4	S.F.	4782	3672	4206	0	6
	Plumbing							
6	Bathtub, soaking, acrylic, w/pop-up drain 66″ × 36″ × 20″ deep	5	Each	32	24	28	1675	10
7	Sink, with trim, porcelain enamel on cast iron, 22″ × 19″, single bowl	6	Each	32	24	28	690	8
8	Bath faucet, diverter spout combination	7	Each	32	24	28	86	10
9	Water closets, bowl only, with flush valve, seat, 1.6 gpf, wall hung	8	Each	32	24	28	970	9
	Electricity							
10	Switch plates, 1 gang, 2 switch, plastic	9	Each	90	112	102	5	9
11	Receptacle, duplex, 120 volt, grounded, 15 amp	10	Each	96	72	84	1.3	9
12	Interior lighting fixtures	11	Each	192	144	168	75	10

Table 1. *Cont.*

Activity Number (i)	Activity Description	Predecessor Activities (P_i)	Unit of Measurement	Quantity of Work per Floor ($Q_{i,f}^{h}$)			Material Cost (M_i) ($)	Maximum Available Crews for Each Hotel (A_i^h)
				Hotel 1	Hotel 2	Hotel 3		
	Painting							
13	Paint interior, and exterior walls, complete, including surface prep, primer and 2 coats finish for all rooms	12	S.F.	2534	1932	2226	0.21	6
	Flooring							
14	Ceramic tiles, recycled glass, standard colors, 2″ × 2″	13	S.F.	2080	1560	1820	22	7
15	Sheet carpet, Nylon, level loop, 28 oz., light to medium traffic	14	S.F.	4782	3672	4206	39.5	10
	Furniture							
16	Hotel Furniture, Standard quality set, minimum	15	Each	32	24	28	2550	8

* S.F. stands for square feet. ** Each stands for each floor in all three hotels.

Table 2. Feasible alternatives for overtime use.

Activity (i)	Feasible Alternative (x_i)	Daily		
		Overtime Hours (hour/day)	Output Rate (OR_{x_i}) (unit/day)	Cost Rate (C_{x_i}) ($/day)
1	1	0	675	667
	2	2	803	1001
	3	4	932	1334
2	1	0	4	521
	2	2	5	781
	3	3	5	911
3	1	0	8	521
	2	3	10	911
4	1	0	8	521
	2	4	11	1042
5	1	0	5000	683
	2	2	5950	1025
	3	3	6975	1366
6	1	0	5.5	942
	2	3	7	1648
7	1	0	8	941
	2	3	10	1646
	3	4	11	1882
8	1	0	8	521
	2	4	11	1042
9	1	0	5.8	938
	2	3	7	1641
10	1	0	80	487
	2	2	95	731
	3	4	110	974
11	1	0	40	489
	2	3	51	856
12	1	0	6	756
	2	4	8	1512
13	1	0	325	358
	2	3	418	627
14	1	0	190	706
	2	2	226	1058
	3	3	244	1235
15	1	0	75	394
	2	2	89	591
	3	4	104	788
16	1	0	10	158
	2	3	13	276

Table 3. Renovation work disruption cost.

Activity Number (i)	Daily Renovation Work Disruption Cost (DPC_i) ($/day)				
	One Week or Less	Two Weeks	Three Weeks	Four Weeks	Five Weeks or More
1	500	334	233	133	0
2	391	260	182	104	0
3	391	260	182	104	0
4	391	260	182	104	0
5	512	342	239	137	0
6	706	471	330	188	0
7	706	470	329	188	0
8	391	260	182	104	0
9	703	469	328	188	0
10	365	244	171	97	0
11	367	245	171	98	0
12	567	378	265	151	0
13	269	179	125	72	0
14	529	353	247	141	0
15	295	197	138	79	0
16	118	79	55	32	0

Table 4. Daily occupancy rates before renovation for sample days.

Hotel No. (h)	Floor No. (f)	Daily Occupancy Rate before Renovation ($BO_{f,n}^{h}$) (%)							
		Monday	Tuesday	...	Saturday	Sunday	...	Thursday	Friday
		16 January 2023	17 January 2023		29 July 2023	30 July 2023		21 December 2023	22 December 2023
1	1	87	91		58	58		91	74
	2	89	93		61	61		93	76
	3	90	95		63	63		95	79
	4	92	97		67	67		97	80
	5	93	98		71	71		98	80
	6	97	100		71	71		100	81
	7	100	100		72	72		100	82
	8	100	100		74	74		100	84
	9	100	100		76	76		100	86
	10	100	100		81	81		100	88
2	1	76	76		58	81		73	59
	2	73	75		58	80		77	61
	3	78	77		56	77		80	59
	4	81	73		56	75		82	56
	5	82	81		64	77		73	69
	6	98	93		69	88		89	65
	7	92	93		63	99		83	69
	8	91	83		64	84		89	67
	9	87	94		72	90		89	68
	10	92	94		72	95		93	66
	11	96	91		84	96		89	77
	12	89	97		76	93		83	80
	13	96	100		73	96		95	74
	14	94	85		77	83		93	77
	15	87	99		76	93		94	83
3	1	63	68		93	69		71	91
	2	61	67		96	67		64	79
	3	64	71		80	63		66	90
	4	63	67		85	64		64	78
	5	65	63		92	64		71	99
	6	68	68		87	71		64	85
	7	66	74		82	69		62	81
	8	67	69		84	61		67	78
	9	66	63		86	60		64	88
	10	62	65		83	61		73	85
	11	69	75		81	64		63	89
	12	70	62		90	68		65	85

Table 5. Daily occupancy rates after renovation for sample days.

Hotel No. (h)	Floor No. (f)	Daily Occupancy Rate after Renovation ($AO_{f,n}^{h}$) (%)							
		Monday	Tuesday	...	Saturday	Sunday	...	Thursday	Friday
		16 January 2023	17 January 2023		29 July 2023	30 July 2023		21 December 2023	22 December 2023
1	1	90	94		60	60		94	76
	2	92	96		63	63		96	78
	3	93	98		65	65		98	81
	4	95	100		69	69		100	82
	5	96	100		73	73		100	82
	6	100	100		73	73		100	83
	7	100	100		74	74		100	84
	8	100	100		76	76		100	87
	9	100	100		78	78		100	89
	10	100	100		83	83		100	91

Table 5. *Cont.*

Hotel No. (h)	Floor No. (f)	Daily Occupancy Rate after Renovation ($AO_{f,n}^{h}$) (%)							
		Monday	Tuesday	...	Saturday	Sunday	...	Thursday	Friday
		16 January 2023	17 January 2023		29 July 2023	30 July 2023		21 December 2023	22 December 2023
2	1	80	80		61	85		77	62
	2	77	79		61	84		81	64
	3	82	81		59	81		84	62
	4	85	77		59	79		86	59
	5	86	85		67	81		77	72
	6	100	98		72	92		93	68
	7	97	98		66	100		87	72
	8	96	87		67	88		93	70
	9	91	99		76	95		93	71
	10	97	99		76	100		98	69
	11	100	96		88	100		93	81
	12	93	100		80	98		87	84
	13	100	100		77	100		100	78
	14	99	89		81	87		98	81
	15	91	100		80	98		99	87
3	1	67	73		100	74		76	97
	2	65	72		100	72		68	85
	3	68	76		86	67		71	96
	4	67	72		91	68		68	83
	5	70	67		98	68		76	100
	6	73	73		93	76		68	91
	7	71	79		88	74		66	87
	8	72	74		90	65		72	83
	9	71	67		92	64		68	94
	10	66	70		89	65		78	91
	11	74	80		87	68		67	95
	12	75	66		96	73		70	91

Table 6. Average daily rate before renovation for sample days.

Hotel No. (h)	Floor No. (f)	Average Daily Rate before Renovation ($BDR_{f,n}^{h}$) ($/day)							
		Monday	Tuesday	...	Saturday	Sunday	...	Thursday	Friday
		16 January 2023	17 January 2023		29 July 2023	30 July 2023		21 December 2023	22 December 2023
1	1	3040	3040		2584	2584		3040	2584
	2	3040	3040		2584	2584		3040	2584
	3	3040	3040		2584	2584		3040	2584
	4	3040	3040		2584	2584		3040	2584
	5	3040	3040		2584	2584		3040	2584
	6	3040	3040		2584	2584		3040	2584
	7	3040	3040		2584	2584		3040	2584
	8	3040	3040		2584	2584		3040	2584
	9	3040	3040		2584	2584		3040	2584
	10	3040	3040		2584	2584		3040	2584
2	1	3408	3408		2880	3408		3408	2880
	2	3408	3408		2880	3408		3408	2880
	3	3408	3408		2880	3408		3408	2880
	4	3408	3408		2880	3408		3408	2880
	5	3408	3408		2880	3408		3408	2880
	6	3408	3408		2880	3408		3408	2880
	7	3408	3408		2880	3408		3408	2880
	8	3408	3408		2880	3408		3408	2880
	9	3408	3408		2880	3408		3408	2880
	10	3408	3408		2880	3408		3408	2880
	11	3408	3408		2880	3408		3408	2880
	12	3408	3408		2880	3408		3408	2880
	13	3408	3408		2880	3408		3408	2880
	14	3408	3408		2880	3408		3408	2880
	15	3408	3408		2880	3408		3408	2880

Table 6. *Cont.*

Hotel No. (h)	Floor No. (f)	Average Daily Rate before Renovation ($BDR^{h}_{f,n}$) ($/day)							
		Monday	Tuesday	...	Saturday	Sunday	...	Thursday	Friday
		16 January 2023	17 January 2023		29 July 2023	30 July 2023		21 December 2023	22 December 2023
3	1	3332	3332		4172	3332		3332	4172
	2	3332	3332		4172	3332		3332	4172
	3	3332	3332		4172	3332		3332	4172
	4	3332	3332		4172	3332		3332	4172
	5	3332	3332		4172	3332		3332	4172
	6	3332	3332		4172	3332		3332	4172
	7	3332	3332		4172	3332		3332	4172
	8	3332	3332		4172	3332		3332	4172
	9	3332	3332		4172	3332		3332	4172
	10	3332	3332		4172	3332		3332	4172
	11	3332	3332		4172	3332		3332	4172
	12	3332	3332		4172	3332		3332	4172

Table 7. Average daily rate after renovation for sample days.

Hotel No. (h)	Floor No. (f)	Average Daily Rate after Renovation ($ADR^{h}_{f,n}$) ($/day)							
		Monday	Tuesday	...	Saturday	Sunday	...	Thursday	Friday
		16 January 2023	17 January 2023		29 July 2023	30 July 2023		21 December 2023	22 December 2023
1	1	3557	3557		3023	3023		3557	3023
	2	3557	3557		3023	3023		3557	3023
	3	3557	3557		3023	3023		3557	3023
	4	3557	3557		3023	3023		3557	3023
	5	3557	3557		3023	3023		3557	3023
	6	3557	3557		3023	3023		3557	3023
	7	3557	3557		3023	3023		3557	3023
	8	3557	3557		3023	3023		3557	3023
	9	3557	3557		3023	3023		3557	3023
	10	3557	3557		3023	3023		3557	3023
2	1	3919	3919		3312	3919		3919	3312
	2	3919	3919		3312	3919		3919	3312
	3	3919	3919		3312	3919		3919	3312
	4	3919	3919		3312	3919		3919	3312
	5	3919	3919		3312	3919		3919	3312
	6	3919	3919		3312	3919		3919	3312
	7	3919	3919		3312	3919		3919	3312
	8	3919	3919		3312	3919		3919	3312
	9	3919	3919		3312	3919		3919	3312
	10	3919	3919		3312	3919		3919	3312
	11	3919	3919		3312	3919		3919	3312
	12	3919	3919		3312	3919		3919	3312
	13	3919	3919		3312	3919		3919	3312
	14	3919	3919		3312	3919		3919	3312
	15	3919	3919		3312	3919		3919	3312
3	1	3998	3998		5006	3998		3998	5006
	2	3998	3998		5006	3998		3998	5006
	3	3998	3998		5006	3998		3998	5006
	4	3998	3998		5006	3998		3998	5006
	5	3998	3998		5006	3998		3998	5006
	6	3998	3998		5006	3998		3998	5006
	7	3998	3998		5006	3998		3998	5006
	8	3998	3998		5006	3998		3998	5006
	9	3998	3998		5006	3998		3998	5006
	10	3998	3998		5006	3998		3998	5006
	11	3998	3998		5006	3998		3998	5006
	12	3998	3998		5006	3998		3998	5006
	13	3998	3998		5006	3998		3998	5006
	14	3998	3998		5006	3998		3998	5006
	15	3998	3998		5006	3998		3998	5006

The optimal renovation plan generated by the developed model for this application example recommends (1) optimal selection of first hotel ($R_1 = 1$) and third hotel ($R_3 = 1$) for renovation during the upcoming fiscal year, as shown in Table 8, (2) optimal renovation start date for each floor in the selected hotels (S_f^h), as shown in Table 8, (3) optimal use of overtime hours (x_i^h) and number of assigned crews for each activity in the selected hotels (C_i^h), as shown in Table 9, and (4) optimal renovation order for each floor in the selected hotels (O_f^h), as shown in Table 8. This optimal renovation plan provided a maximum total net profit of $28,975,181 for the upcoming fiscal year that represents the difference between maximum total revenue of $40,645,527 for all three hotels ($h = 1,\ 2,\ \&3$) and a minimum total renovation cost of $11,670,347 to renovate the first and third hotels ($h = 1\ \&\ 3$).

Table 8. Optimal hotel selection, floor start date, and floor renovation order.

Optimal Hotel Selection (R_h)	Floor No.	Optimal Floor Start Date (S_f^h)	Optimal Floor Order (O_f^h)
1	1	109.9	10
	2	109.6	9
	3	109.3	8
	4	42.6	6
	5	109.0	7
	6	42.3	5
	7	0.0	1
	8	0.6	3
	9	0.3	2
	10	42.0	4
3	1	1.5	5
	2	2.1	7
	3	1.3	4
	4	32.5	10
	5	1.8	6
	6	33.1	12
	7	0.0	1
	8	1.0	3
	9	32.8	11
	10	0.3	2
	11	32.3	9
	12	32.0	8

Table 9. Optimal overtime use and number of crews.

Activity Number (i)	Optimal Overtime Use Alternative (x_i^h)		Optimal Number of Crews (C_i^h)	
	Hotel 1	Hotel 3	Hotel 1	Hotel 3
1	1	1	9	5
2	2	2	10	10
3	1	1	10	10
4	1	1	10	10
5	1	1	4	5
6	1	1	10	10
7	1	1	8	8
8	1	1	8	9
9	1	1	10	9
10	1	1	5	6
11	1	1	9	6
12	1	1	10	10
13	1	1	6	6
14	1	1	6	5
15	2	2	10	10
16	2	2	6	5

8. Discussion

To highlight the novelty of the developed optimization model, the same application example was analyzed using 10 different traditional planning scenarios where each one represents a possible set of selections for each of the four planning decisions: hotel renovation selection, floor renovation order, use of overtime hours, and number of assigned crews. First, all hotel selection combinations were analyzed in these 10 different scenarios by either selecting all hotels, first and second hotels, first and third hotels, or second and third hotels to be renovated during the upcoming fiscal year. Second, ascending and descending floor renovation orders were analyzed in these scenarios where renovation crews can start working either from the first to the top floor, or from the top to the first floor. Third, two overtime use alternatives were considered in these scenarios which either involve maximum overtime use, or no overtime use for all renovation activities. Fourth, the number of assigned crews were randomly selected from either maximum, half, or minimum number of available crews. This sample of 10 possible renovation plans were analyzed and compared to the optimal renovation plan, as shown in Table 10. The results of this comparison illustrate that (1) two of the considered renovation plans were infeasible because their total renovation cost exceeded the allocated renovation budget of $12.5 M; and (2) all 10 possible renovation plans underperformed the generated optimal solution as they all provided lower net profits compared to the optimal plan that ranged from $1,277,967 (4%) to $9,677,435 (33%), as shown in Table 10. This illustrates the novel contributions of the present model and its unique capabilities of identifying optimal renovation planning decisions for hotel selections, floor renovation start dates, use of overtime hours and number of assigned crews, and floor renovation order. These optimal renovation decisions enable planners to maximize hotel revenues during renovation work while minimizing hotel renovation cost.

Table 10. Sample set of possible renovation plans.

Renovation Plan (p)	Set of Possible Renovation Planning Decisions: Hotel Renovation Selection (R_h)	Floor Renovation Order (O_f^h)	Overtime Hours Alternative (x_i^h)	Number of Crews for Each Activity (C_i^h)	Net Profit Performance: Hotel Revenues ($)	Renovation Cost ($)	Net Profit ($)	Loss in Net ProfitCompared to Optimal Renovation Plan [a] ($)	(%)
1	1 2 3	Ascending	No overtime	Max	Infeasible solution *				
2	1 2	Ascending	No overtime	Max	38,882,673	12,042,991	26,839,682	2,135,499	7
3	1 3	Ascending	Max overtime	Max	39,262,750	11,565,566	27,697,214	1,277,967	4
4	1 2	Descending	Max overtime	Max	Infeasible solution **				
5	2 3	Ascending	No overtime	Max	38,413,047	12,342,433	26,070,614	2,904,567	10
6	1 3	Descending	Max overtime	Half	37,497,125	12,207,775	25,289,350	3,685,832	13
7	1 3	Descending	No overtime	Half	35,452,997	11,593,667	23,859,331	5,115,850	18
8	1 2	Ascending	No overtime	Half	35,166,837	12,069,883	23,096,954	5,878,227	25
9	2 3	Ascending	No overtime	Half	33,589,751	12,367,586	21,222,165	7,753,016	27
10	1 3	Ascending	No overtime	Min	31,276,431	11,978,686	19,297,746	9,677,435	33
11 [a]	**1 and 3**	**Optimal**	**Optimal**	**Optimal**	**40,645,527**	**11,670,347**	**28,975,181**	**0**	**0**

* Infeasible plan because renovation cost exceeds allocated budget of $12.5M when selecting all three hotels for renovation. ** Infeasible plan because renovation cost exceeds allocated budget of $12.5M due to additional cost of overtime premiums. [a] Optimal renovation plan generated by developed model.

9. Conclusions

A novel model was developed for optimizing the planning of hotel renovation projects to maximize hotel revenues during renovation work while minimizing project cost. The present model computations are performed in three main modules: optimization module that searches for and identifies an optimal renovation plan to maximize hotels net profit during any fiscal year; scheduling module that computes the start and finish dates as well as total work disruption time for each renovation activity in all hotels; and hotel profit module that calculates total hotel revenues and total renovation cost for each generated renovation plan in the optimization module. To highlight the novel contributions of the developed model, an application example of three hotels was analyzed. The outcome of this analysis confirms that the developed model was capable of identifying optimal selection of hotels to be renovated during a fiscal year based on allocated renovation budget, optimal floor renovation start date in each hotel, optimal use of overtime hours and number of assigned crews for each renovation activity, and optimal floor renovation order in each hotel. This novel methodology and its original capabilities are expected to provide much-needed support for renovation planners who seek to maximize hotel revenues while minimizing their renovation cost.

Despite the aforementioned contributions and capabilities of the developed model, its current scope has two main limitations: (1) ignoring the impact of uncertainty in labor productivity, floor occupancy rates, and floor daily rates that are often encountered in hotel renovation projects, (2) focusing on quantifying the impact of the five main decision variables of hotel renovation selection, floor renovation start date, use of overtime, number of assigned crews, and floor renovation order and not considering other decision variables that may affect the hotel renovation cost, such as decisions about material deliveries and multiple working shifts of crews. To address these limitations, the developed model can be expanded in future research studies to: (1) consider the impact of uncertainty in labor productivity, floor occupancy rates, and floor daily rates, and (2) expand the model formulation to include additional decision variables, such as decisions about material deliveries and crews working multiple shifts.

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