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A New Queuing-Based Mathematical Model for Hotel Capacity Planning: A Genetic Algorithm Solution

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ABSTRACT

This study presents a new mathematical optimization model using queuing theory to determine the hotel capacity in an optimal manner. For this purpose, a Knapsack model based on the queuing theory is proposed. In this regard, after simulating a hotel's reception system with the help of queuing models and using a limited two-dimensional Knapsack model, the capacity and an optimum number of rooms are obtained. Since the proposed model is too complex on large scales, a modified Genetic Algorithm (GA) approach enhanced by Taguchi method is employed to solve the problem. The obtained results indicate that unlike previous studies, the proposed models can be applied to different scenarios.

1. Introduction

Today, tourism is more than an industry, and as a dynamic global and social phenomenon has its subtleties. In recent years this industry has had a great impact on the economic, social, and cultural aspects of world such as job opportunities, exchange technology, regional balance, contributing to world peace, and contribute to the investment in cultural heritage. Now tourism is the largest part of the service industry and as one of the three most important and profitable industry after oil and car industry which according to predictions, in less than two decades in terms of revenue it will be in first place [1].

Tourism is composed of elements and activities that directly or indirectly affect this industry. Hotels and accommodation centers are the most important elements that we can mention. In fact, hospitality and tourism are correlative to each other and strengthening both will be necessary for development and progress. While the term tourism evokes economic prosperity and social development, by observing tourist attracting cities in Iran like Mashhad, Shiraz, it raises a question that when the tourist travels rate is at the peak and also when it is on the lowest rate what positive impacts will result for this kind of

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cities. This problem is considerable and expandable on both the macro and micro perspective. On the macro and strategic plans and long-term, it can be argued that since the rate of arrival of the travelers and tourists (from different points of land, rail, sea, and air) to Touristic Cities is known and also considering the guest's stay time in residential centers of these cities during different periods of the year, is the current capacity of residential centers for the reception and accommodation of guests sufficient? The following questions can be raised as another form of the first question: What level of service capacity at different periods of the year should be provided for guests? How much is the probability of facing a shortage in capacity on different periods of time? According to the prediction done in relation to guest's arrival rate and duration of stay, for coming years, is there a need to change the capacity of residential centers [2]?

Now, if we look from the micro perspective to this issue, people applying to build, buy or rent hotel, and according to their ability to attract guests using different ways (telephone booking, online, intermediaries and travel companies and tourism), this question will arise that what capacity and how many rooms to build or buy are needed for their hotel in order to obtain the maximum profits? In fact, is there a model that could help the investors to choose the optimal capacity to build, buy or rent a hotel in this area? According to the above-mentioned issue, the purpose of this paper is to provide a combined model of fundamentals of queuing models that help to achieve the optimal capacity of residential centers.

The structure of this paper is as follows: First in the Section 2, the literature review for the problem of determining the optimal capacity of the hotel is reviewed. The Section 3 outlines the proposed model and cost function component provided in the model and it is expressed how to simulate the reception system of the hotel using the queuing models. In the Section 4, innovative approaches and meta-heuristic methods are used to determine the capacity of the hotel problems for large-scales. In the Section 5 to clarify the proposed model, a numerical example for both small and large-scale problem is solved and the results are elaborated. Finally, in Section 6, the conclusion and suggestions for future research are provided.

2. Literature Review

Investigating the relevant literature demonstrates that some researchers defined capacity management as demand management and others defined it as capacity and demand management. However, both demand management and capacity management should be considered as two distinct concepts. In demand management, we try to take the timing of customers' needs and the volume demanded by the customers under management control organizations using marketing strategies [3]. On the other hand, capacity management ensures that sufficient capacity will be there to meet and respond to the market needs [4]. Capacity decision-making is one of the main strategies concerning the industrial managers which will affect an industry's respond in marketing the needs in the present and future [5]. Most of the previous researches on capacity studies, each have looked into a specific approach to the issue of capacity management in different industries. For example, in the tourism industry, most investigators have focused on the issue of capacity management with revenue management approach [6]. However, the literature suffers from the lack of analysis of the spectrum, in the area of capacity management for different industries [7]. Also, the number of studies in services field shows its importance. Because in most services areas service capacity impacts on the customer satisfaction and the level of service delivered to them. As a result, in areas such as hospitals, car parking, restaurants, hotels and residential centers, determining the optimal capacity have been mentioned. However, in the manufacturing facilities some researchers have been done in determining the optimal capacity, for example, we can refer to determining the optimal storage capacity models.

For instance, Khalili and Lotfi [8] reviewed the problem of determining the optimum storage capacity for fuzzy probabilistic demand and they proposed a solution to this problem using fuzzy programming model and queuing theory. They considered warehouses construction cost, holding cost. Rao and Rao [9] examined storage capacity on a single product model with variable costs over time, savings from investment and operating costs in probabilistic condition. They provided structure to achieve the optimum solution and showed that the storage size problem in the static state and its developments can be easily solved without having to apply common linear programming. They solved store size problem in dynamic mode with the help of network flow algorithm and using dynamic programming.

Also in the hospital area, according to the high cost of preparing and equipping the operating rooms, many studies have been conducted to determine the optimum number of operating rooms. Several methods have been proposed in this study to determine the optimal capacity such as discrete simulation methods, stochastic simulation, queuing theory-based methods and combination methods [10-15]. For example, Kokangul [16] offered a model to optimize the capacity beds of a hospital unit, using a combination of deterministic and stochastic methods where the number of patient and stay time of each one was modeled as random processes. In this study according to key parameters presented such as service level, employment level and rate of patient reception, and using data obtained through simulation, a nonlinear mathematical model to determine the optimal capacity is provided. In the problem capacity management of the restaurant, we can imply to Hwang et al. [17] study where they used the relevant queuing models to formulate a local restaurant system and then attempted to solve the model in order to maximize profits and increase customer satisfaction.

Furthermore, Pullman and Rodgers [7] had a good review of studies conducted on the subject of hotel capacity management. They categorized capacity management in two fields of physical capacity and required human resources capacity. Moreover, they examined the decision-making problem to manage capacity in two categories of strategic decisions and short-term decisions sectors. They also classified the studies in terms of solutions.

In relation to determining hotel's optimal capacity some studies have been done. Gu [18] tried to analyze and optimize the hotel's capacity problems in Las Vegas by using an inventory model. According to him, if we assume the empty rooms at per night as the products of the hotel, then in case of rooms be empty, these will be considered as deteriorated products in manufacturing units. In another study, Chen and Lin [19] examined the effects of uncertain demand on hotel’s capacity by using collected information from touristic hotels' in Taiwan in years 1998 to 2008. They first obtain random demand in each period by using an autoregressive equation. Then, they applied random demand with another factor in a regression equation to predict the required capacity for the new period. Ben-David et al. [20] minimized the gap between the actual and the optimal number of tourists in order to get as close as possible to the optimally desired number. In their view, the actual number of tourists from each country is affected by the cost of travel as well as by exogenous variables. They planned a system of two simultaneous equations, where the number of tourists and the cost of travel are the endogenous variables. They estimated the system for incoming tourism to Spain from various countries and forecasted the actual number of incoming tourists. The paper [21] raises the issue of determining the optimal capacity supplied at every period in the case in which demands fluctuate with peak (high) demand, H, followed by off-peak (regular or low) demand. The authors of this article believe that the profit maximizer who faces in every cycle peak and off-peak demands, may incur costs due to high capacity on one hand, and extra profit in a peak period, combined with too much production in the off-peak period on the other hand. They presented two cases. In Case 1 it is not possible to transfer partial demand from a peak period to an off-peak period. In Case 2, it is possible because of the readiness of customers to transfer their demands from a peak to an off-peak period. The paper [22] studies joint dynamic pricing and capacity control for hotel and rental operations when Advanced Demand Information (ADI) is available for some but not all customers. The authors of this paper considered dynamic pricing for non-ADI customers and capacity control for ADI customers with a stochastic dynamic programming model. They examined structural properties and fully characterized optimal policies. Based on monotone properties of optimal policies, they developed effective pricing and rationing heuristics, and investigated the value of demand information through numerical studies. In another research [23], the author demonstrated that demand uncertainty affects market structure in meaningful ways. The most robust evidence is in support of market-level uncertainty yielding larger hotels. He also provided some evidence that within-market, hotel-specific increases in demand uncertainty also yield increases in capacity. He also showed evidence that suggests the presence of uncertainty may reduce the number of hotels, even if each hotel is, on average, larger in size. This ultimately means the effect of demand uncertainty on total room capacity, in equilibrium, in indeterminate. The omitted key supply variable from his analysis is the cost of building capacity, though the fixed cost of entry also matters. Obviously, it matters for my discussion of the number of properties and market structure more generally, but it matters for a single hotel’s capacity choice as well, if fixed costs are high, entry will likely be less frequent, but hotels will be larger conditional on entry. As a result, high fixed costs, if they are correlated with my measure of uncertainty, would yield similar patterns of larger and fewer hotels in certain markets. Madanoglu and Ozdemİr [24] presented one of the first studies on the relationship between meeting space capacity and hotel operating performance. They found that the relationship between these two variables is non-linear. Therefore, how much meeting space hotels should offer to improve their operating performance remains unclear. However, their findings demonstrated that meeting space capacity has a positive influence on hotel operating performance after a certain threshold is reached. Therefore, each hotel may have a specific optimal point that leads to better operating performance. This optimal point may be a function of hotel (e.g., size, age, and affiliation) and market (e.g., location, level of competition, and types of guests) characteristics. In another paper, Pan [25] due to rapid changes in demand and taking into account the capacity of the hotel room, the model has to determine the optimal rate for hotel rooms. It is worth mentioning that determining the optimal rate of hotel rooms and hotel revenue management model is provided by many other researchers [26-30].

In Iran, for determining the optimal hotel capacity, a few studies have been done. For example, Khataei et al. [31] measured the performance of some of the hotels in Tehran in their paper using DEA method which is one of the cases examined to measure hotel performance. Feiz and et al. [32] also conducted a study on hotels in Mashhad to examine the quality of service and customer satisfaction which is one of the criteria considered in relation to the hotel's capacity services provided for accepting guests. Taheri Demneh et al. [2] reviewed the current capacity constraints of accepting guests in Shiraz hotels and they reported lost profits due to the shortage of hotel's capacity.

Review of relevant studies regarding the management of hotel capacity refers to the extreme poverty of studies in this area. It also worth mentioning that in this limited studies models have been offered, that’s just supposed to be used for a series of specific circumstances and with the slightest changes in the assumptions, lose their effectiveness. For this reason, this study aims to propose a knapsack model by applying queuing theory principles to optimize the hotel capacity planning. Application of queuing models due to high variability, as well as the power to create new models using Markov chains, enables compliance the proposed model with real conditions.

The main contribution of the current research is that the objective function of our proposed model is developed based on the newsvendor model basics, a model in inventory management context, and combining its features with a well-known queuing discipline, m/m/k, for the purpose of optimal capacity planning. More specifically, the equilibrium equations and probabilities in queuing theory are used for computing the penalty of unmet demand (shortage of capacity or excess capacity). Applying the queuing systems theory in formulating the objective function and considering the time value of money has differentiated this study with the earlier conducted studies in the area of hotel capacity management and has resulted in more reliable findings in this regard.

Using queuing models to calculate the amounts of the objective function in the proposed model which is the contribution of this research has some advantages over the traditional models. Simplicity and comprehensibility of queuing theory from one side and diverse number of queuing models from the other side have led to the easy application of the proposed model in a vast variety of situations over diverse hotels. However, most of the existing models are only applicable to a specific situation and could not be extended to different situations.

3. Proposed Mathematical Model

Given that the proposed model is based upon the concept of queuing model, it is essential that hotel and reception systems be in sync with the components of a queuing system. For this reason and for synchronization purposes we consider the following issues:

- Hotel guests are considered as customers in the queuing system, arriving at the hotel with the rate of λ_j, to stay in *j* type hotel rooms.
- Hotel rooms are considered as service providers in the queuing system, so the number of hotel rooms is equivalent to the number of service providers in the queuing system.
- The average staying duration of hotel guests in the type *j* rooms is equivalent to the inverse of service rate of service providers in the queuing system for customers which is shown by $\frac{1}{\mu_j}$.
- The average number of filled type *j* hotel rooms equals the average number of customers in the simulated queuing system which is shown by L_j.

3.1. Assumptions and Notations

The mathematical model in this paper is developed with the following assumptions:

- The time interval between the arrival of the guests seeking accommodation in type *j* hotel rooms and duration of their staying at the hotel has an exponential distribution.
- Investors have investment restrictions for hotel construction and they can invest in the maximum amount of B_{max}.
- Investors have space restrictions for hotel construction and the maximum available space is S_{max}.
- Hotel has three types of rooms to accommodate guests. Suite *(j = 1)*, one bedroom *(j = 2)* and a two-bedroom *(j = 3)*.

3.2. Model Parameters

B_{max}: Maximum initial capital for construction of a hotel.

S_{max}: The maximum initial available space to build a hotel.

a_j: Required space allocated to a type *j* room.

b_j: Required investment for a type j room.

π_{n_j}: The possibility of the occupation of n j-type rooms in the long run (the percentage of time that the hotel has *n j*-type rooms filled with guests).

λ_j: Arrival rate of guests in the hotel's type *j* room.

μ_j: Service rate of guests in the hotel's type *j* room.

P_j: Gained revenue from every type *j* room for a one-night stay of guests.

i: Interest rate.

N: The number of cycles in the planning horizon.

3.3. Model Formulation

The model proposed in this study is formulated as ***Eqs. (1)- (4)***.

Notably, guests booking system and acceptance for each of the three hotel rooms is a queuing system M/M/$\mathrm{k_j}$, where the interval between the arrival of the guests and the duration of their stay at the hotel follows an exponential distribution. And k_j (type j room) service providers is intended to serve customers of this queue system (guests). The aim is to determine the optimum number of each type of rooms, which is k_j^* *s*, while the restrictions on the amount of investment and available space are satisfied and also imposed costs on investors are minimized.

$$\text{Min } C_T = \sum_{j=1}^{3}\left[\left[\frac{i.(1+i)^N}{(1+i)^N-1}\right].\sum_{n=0}^{K_j}\left(K_j-n\right).\pi_{nj}.b_j+\sum_{n=K_j+1}^{\infty}\left(n-K_j\right).\pi_{nj}.P_j\right] \tag{1}$$

s.t.

$$\sum_{j=1}^{3} a_j K_j \le S_{max}, \tag{2}$$

$$\sum_{j=1}^{3} b_j K_j \le B_{max}, \tag{3}$$

$$K_j \ge 0 \text{ ,Integer} \qquad \forall \ j \in J. \tag{4}$$

Eq. (4) shows that the capacity of three types of rooms which is also decision variable of the problem must be a positive integer. ***Eqs. (2) & (3)*** are in relation to maximum investment and maximum available space restriction and they cause the total space and total cost, required to create optimal capacities for Triple rooms, do not exceed the maximum available space and capital. ***Eq. (1)*** also related to the cost function of proposed model that we seek to minimize. The cost function is the sum of two different costs. Cost of the first part is due to allocating required capacity more than the optimal size($k > k^*$). In fact, if a hotel with very high capacity is constructed, in most cases part of the hotels capacity will remain empty and due to stagnant of capital and losing other investment opportunities, investors will be subject to a great cost and yet, the performance of this hotel with this large number of the room will be low. This cost is known as excess capacity cost and it will be obtained from the ***Eq. (5)***.

$$\sum_{n=0}^{K_j} \left(K_j - n\right).\pi_{nj}.b_j. \qquad (5)$$

Cost of the second part is due to allocating required capacity less than the optimal size ($k < k^*$). In fact, if a hotel with a small capacity be constructed, in most cases, the hotel will be entirely booked and it will not be able to accept and accommodate more guests. In this case, we face a kind of lost profit per lost customer. This lost profit is known as capacity shortage cost and it will be obtained from the ***Eq. (6)***.

$$\sum_{n=K_j+1}^{\infty} \left(n - K_j\right).\pi_{nj}.P_j. \qquad (6)$$

It is shown that by changing the capacity of the hotel, this two costs will change in the opposite direction. In fact, with an increase in capacity, excess capacity costs will be increased and capacity shortage costs will be reduced, and vice versa (***Fig. 1***).

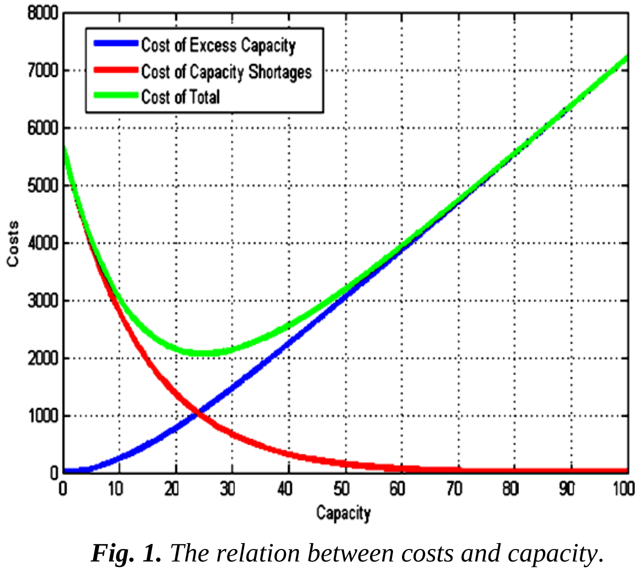

Fig. 1. *The relation between costs and capacity.*

The total cost function of the construction of the hotel C_T with a capacity of suboptimal ($k \neq k^*$), can be achieved from the sum of the cost of excess capacity and capacity shortage. Of course, the cost of creating excess capacity is imposed, only once, at the beginning of the planning horizon, when we decide to build, buy or rent the hotel. While the capacity shortage cost shall be paid during in each period of the planning horizon. In order to compare the two costs it is necessary to distribute the cost excess capacity, while taking the time value of money into account, between the periods of planning horizon, so that both the costs become to uniform periodic costs. For this purpose, we will multiple the excess capacity cost in the Capital Recovery Factor (CRF).

$$CRF = \left(\frac{A}{P}, i, N\right) = \frac{i.(1+i)^N}{(1+i)^N - 1}. \tag{7}$$

Finally, in order to obtain the total cost function we sum the costs for each hotel room type (for *j = 1*, *2*, and *3*):

$$C_T = \sum_{j=1}^{3}\left[\left[\frac{i.(1+i)^N}{(1+i)^N - 1}\right].\sum_{n=0}^{K_j}(K_j - n).\pi_{nj}.b_j + \sum_{n=K_j+1}^{\infty}(n - K_j).\pi_{nj}.P_j\right]. \tag{8}$$

Note that the possible values in the objective function π_{n_j} will be obtained based on the Markov chain model in relation to queue model ($M/M/k_j$) and the following equations [33].

$$\pi_{n_j} = \left\{\begin{array}{lll} \left(\frac{\lambda_j}{\mu_j}\right)^{nj} \frac{\pi_{0_j}}{n_j!} & ; & n_j < k_j \\ \left(\frac{\lambda_j}{\mu_j}\right)^{nj} \frac{\pi_{0_j} k_j^{kj-nj}}{k_j!} & ; & n_j \geq k_j \end{array}\right\}. \tag{9}$$

$$\pi_{0_j} = \left[1 + \sum_{n=1}^{k_j-1}\left(\frac{\lambda_j}{\mu_j}\right)^n \frac{1}{n!} + \sum_{n=k_j}^{\infty}\left(\frac{\lambda_j}{\mu_j}\right)^n \frac{1}{k_j!} * \frac{1}{k_j^{\,n-k_j}}\right]^{-1}. \tag{10}$$

By using the ***Eqs. (8) & (9)*** in the ***Eq. (1)***, the new Knapsack model is as follow (***Eqs. (11)- (14)***):

$$\text{Min } C_T = \sum_{j=1}^{3}\left[\begin{array}{l}\left[\frac{i.(1+i)^N}{(1+i)^N - 1}\right].\sum_{n=0}^{K_j}(K_j - n).\left(\frac{\lambda_j}{\mu_j}\right)^{n_j} \frac{\pi_{0_j}}{n_j!}.b_j \\ + \sum_{n=K_j+1}^{\infty}(n - K_j).\left(\frac{\lambda_j}{\mu_j}\right)^{n_j} \frac{\pi_{0_j} k_j^{k_j-n_j}}{k_j!}.P_j\end{array}\right]. \tag{11}$$

s.t.

$$\sum_{j=1}^{3} a_j K_j \leq S_{max}. \tag{12}$$

$$\sum_{j=1}^{3} b_j K_j \le B_{max}. \tag{13}$$

$$K_j \ge 0 \text{ ,Integer } ......\forall \ j \in J. \tag{14}$$

The proposed model is coded and solved via MATLAB software and it will be further discussed in the illustrative example section. The Knapsack model is proven to be considered as an NP-hard problem [34]. Consequently, solving the proposed problem using the exact solving method particularly for large-scale problems in reasonable computational time is impossible. For this reason, we use a meta-heuristic approach based on GA to solve the large-scale model.

4. Solution Approach

In this study, a two-dimensional Knapsack model has been offered to determine the optimal hotel capacity using queuing models. Due to the importance of Knapsack problem, several algorithms have been reported to solve this problem. These algorithms can be classified into two general categories: The exact algorithms and approximation algorithms. Since the Knapsack is an NP-Complete problem, the exact algorithms usually use a branch and cut method or combination methods or dynamic programming. In the worst case, they have exponential complexity and are not suitable for use in practical applications. For this reason, many approximation algorithms to solve Knapsack problem has been reported. Many studies have been done to solve the one-dimensional ($m = 1$) Knapsack problem. Efforts have also been made to solve approximate multidimensional Knapsack problem. For example, approximation algorithms are proposed for solving multi-dimensional Knapsack problem, such as repetitive algorithms. In these methods, achieving an optimal response is not guaranteed, but in most cases generates an acceptable approximate solution. GA is one of the repetitive algorithms that has been applied in various studies [35-39] by the researchers. For the same reason, in this research, GA is used to solve the proposed two-dimensional Knapsack problem.

GA is known as an efficient method for solving optimization problems. GA approach was first presented by Holland [40] in 1975 at the University of Michigan. In 1992, Koza [41] applied this technique to solve and optimize engineering problems and form the GA to computer language for the first time. This section outlines the details of the proposed GA: Chromosome definition (answer code); any repetitive Meta heuristics needs a structure to display (coding) solutions. Encoding has a significant impact on the efficiency and effectiveness of each metaheuristic and is considered as an important step in the design of a Metaheuristics to obtain the initial answer. We generate three (the number of rooms) discrete random integers between zero and n (the maximum number of each type of room).

10	12	8

Fig. 2*. How to display the answer.*

Creating an initial population: The most common method for generating initial population due to the speed of execution and also diversify of the answers is generating random population. So, in this part, we generate random answer considered population number, and then we compute the objective function value for each answer.

4.1. Intersection

To create the intersection, first we generate three (the number of hotel rooms) random integers from a uniform distribution between -gamma and 1+gamma. Then, by multiplying these integers in the parents and rounding those, new children will be generated (see ***Figs. (3)- (7)***):

10	17	25

Fig. 3. *The first parent chromosome.*

15	17	14

Fig. 4. *The second parent chromosome.*

0.25	0.76	1.04

Fig. 5. *Randomly generated integer*.

14	9	16

Fig. 6. *The first child chromosome.*

11	15	22

Fig. 7. *The second child chromosome.*

4.2. Mutation

In order to make random changes in genes' chromosome mutation operator is used this function prevents premature convergence and reduces the likelihood of being trapped in a local optimum answer. To create a mutation, we add a normal random number from ten percent of answer range to a number of randomly selected genes and through comparing this answer to the minimum and maximum acceptable answers, a new answer will be obtained (see ***Figs. (8) & (9)***).

14	18	4

Fig. 8. *The current answer.*

14	18	90

Fig. 9. *A new answer after the mutation.*

4.3. Evaluation and Selection

In every generation, chromosomes fitness measures are evaluated according to the original objective function because we are faced with a minimization problem, we turn the objective function value of each chromosome to the fitness function. In this paper, three kinds of selection mechanism are considered which will be outlined in the next section.

Roulette wheel; the main idea in the roulette wheel is laid beneath these two points:

- The better chromosome has a higher chance.
- Chance of selection of each chromosome is proportional to the fitness amount of that chromosome.

First fitness value will be calculated for each chromosome of the population (chromosomes with higher fitness values will have a higher chance for selection). Then we calculate the cumulative fitting and afterward we divide fitness of each chromosome on the cumulative fitness. In this method, after determination of the probability of chromosomes selection, a random number between 0 and 1 will be generated. Then chromosomes will be reviewed (which are arranged ascending) from top, and the chromosome with cumulative distribution more or equal to generated number will be chosen.

Random method; the easiest way for selecting chromosomes is chosen in this study. The implementation of this method is very simple but its performance is very low. However, in some problems, we can choose to do part of the selection procedure randomly. Because using this method good and bad chromosomes have the same chance of being selected. We may note that in some cases participating a bad chromosome can cause to produce a better chromosome.

Tournament selection; a subset of the attributes of a society (here the objective function value) are elected and its members will compete together according to the set attributes. And finally, the specified number of members of the population (Tournament Size) of each subgroup is selected for reproduction.

4.4. Stopping Condition

Increasing the number of repetitions of the algorithm allows the model to have ample opportunity to solve the problem and therefore larger values of this parameter leads to better results, but it should be noted that by selecting larger amounts the number of iteration and computational time increases for proposed GA algorithm; 200 repeats is assumed and after reaching the 200 iteration algorithm stops. In order to sum up the performance of the proposed algorithm, its flowchart is provided in ***Fig. 10***.

5. Illustrative Example: Hotel Capacity Planning Optimization Problem

5.1. A Small Scale Example

Assume some investors in tourism industry plan to build a five-star hotel in Iran. After finding a location to build the hotel, it is important to decide about the hotel capacity. They would like to obtain the optimal capacity for the constructed hotel considering a 10-year planning horizon. By gathering data from several hotels in the area and analyzing the data, the required information to determine the optimal capacity are shown in ***Table 1***.

5.1.1. Obtained results

By coding the problem in MATLAB software, the cost function values are obtained for various capacities including the capacities which not only satisfy the constraints but also gain the minimum cost function to the investors. The optimal capacities proposed to create a variety of rooms such as suites, one-bed, and double-bed rooms. Output results show the optimal number of hotel rooms is equal to 12 units for suits and the optimum number of one-bed and double-bed rooms are respectively 4 and 8 units. Note that in MATLAB program, the Sigma II upper bound in the cost function must be a large number rather than the (∞) infinity. The large number should be chosen in such a way that the sum of the probabilities is close to one. In the example above we have put 1000 for this number.

$$\sum_{n=0}^{1000} \pi_{n1} = 0.9999 \cong 1,$$
$$\sum_{n=0}^{1000} \pi_{n2} = 0.9999 \cong 1,$$
$$\sum_{n=0}^{1000} \pi_{n3} = 0.9999 \cong 1.$$

Table 1. *The parameters of small-scale example.*

Parameter	Value
N	10*365=3650
i	0.05%
B_{max}	2000000
S_{max}	1000
a_1, a_2, a_3	30,40,60
b_1, b_2, b_3	4500,5500,7000
P_1, P_2, P_3	90,150,200 $
$\lambda_1, \lambda_2, \lambda_3$	(5,2,3)
$\frac{1}{\mu_1}, \frac{1}{\mu_2}, \frac{1}{\mu_3}$	(3.5,2.5,4)

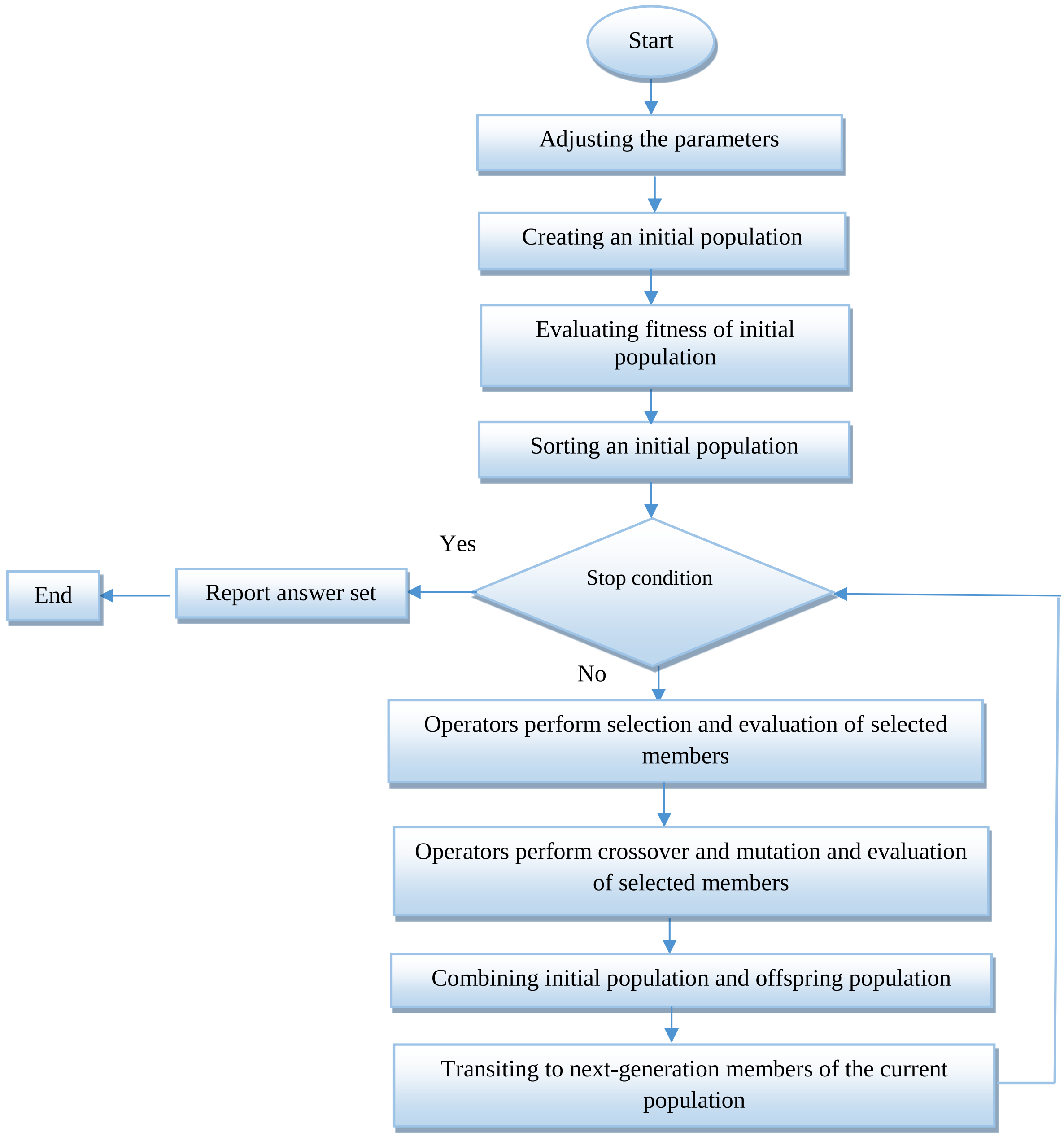

Fig. 10. *GA flowchart.*

In this example, with respect to the values of the arrival rate and stay time of guests, the maximum number of rooms built for each of the triple-bed rooms is considered 50 units $k_j < 50$. Due to the more guest arrival rate, we aimed to solve this problem with considering more room for each triple-bed rooms. Then the code presented in the previous step could not reach to an accurate solution in a reasonable time. Therefore, when we face a large problem we have to use a meta-heuristic method like GA.

5.2. A Large-Scale Example

Input data of the current example is shown in ***Table 2***. Comparing to the aforementioned problem, the arrival rate, as well as the available space and capital for the hotel construction, are increased in this example. Therefore, it is not unusual that the optimum capacity for each of the three rooms is over 50 rooms. So in this sector, the maximum capacity that can be assigned to each of the triple hotel rooms is considered up to 1,000 rooms and we used GA to solve the problem.

Table 2. *The parameters of large scale example.*

Parameter	Value
N	*10*365-3650*
i	*0.05%*
B_{max}	*500000*
S_{max}	*3000*
a_1, a_2, a_3	*30,40,60*
b_1, b_2, b_3	*4500,5500,7000*
P_1, P_2, P_3	*90,150,200 $*
$\lambda_1, \lambda_2, \lambda_3$	*(25,15,10)*
$\frac{1}{\mu_1}, \frac{1}{\mu_2}, \frac{1}{\mu_3}$	*(3.5,2.5,4)*

We compared the performance of the proposed algorithm GA and global solver GAMS. We used the average Relative Percent Deviation (RPD) for comparison purpose. The relative percent deviation was calculated using ***Eq. (15)*** as below:

$$\text{RPD} = \frac{|\text{OV of the metaheuristic} - \text{OV of the best metaheuristic}|}{\text{OV of the best metaheuristic}} * 100\%. \tag{15}$$

5.2.1. Computational results

To solve the problem through GA procedure, it is first required that the parameters are adjusted. For this purpose, Taguchi method is used to set the parameters of the GA. The first objective in designing an efficient parameter is to identify and set the factors that minimize the changes in response variable and the next aim is to identify factors that are controllable and uncontrollable. The last goal of the Taguchi method is to find the optimum combination of controllable factors amount [42] for proposed GA algorithm crossing rate, mutation rate, the percentage of mutation and selection methods parameters must be set. For each input factors, three levels according to previous research and by trial and error are selected. ***Table 3*** shows the levels of selected GA parameter.

Table 3. *Parameters and their levels for GA.*

Factor	**Level 1**	**Level 2**	**Level 3**
Crossover rate	*0.7*	*0.8*	*0.9*
Percent of mutation	*0.1*	*0.2*	*0/3*
Mutation rate	*0/02*	*0/05*	*0/1*
Selection mechanism	*Roulette wheel*	*Tournament*	*Random*

Based on Taguchi's standard table, considering four three-level factors L9 and L27 designs can be used. That in this part we used the L9 design because it is easier less computing. First objective function value is measured for various experiments and then it will be without scale using the standard relative deviation percentage; in the equation 15, the smallest produced amounts is considered as the best answer. ***Fig. 11*** shows the average response for each compound. Since the option ((smaller is better)) has been selected for different levels of response variable, the answers with lower value are considered. Accordingly, suitable compounds based on average response factor are intersection rate: 0.9, mutation percent: 0.3, mutation rate: 0.02, selection mechanism: roulette wheel.

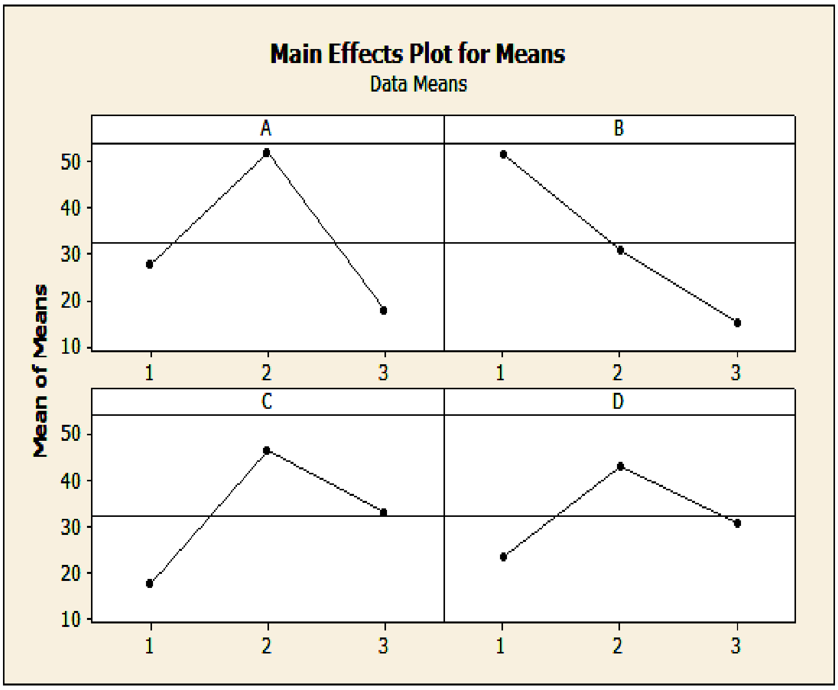

Fig. 11. *Comparison of the average of responses.*

Fig. 12 shows the stability of answer for each compound. Answer stability indicates the strength of considered factors intended to minimize the variability in the process of controlling other uncontrollable factors. Thus, the higher is the stability of a compound; it would be more appropriate compound. Accordingly, suitable compounds based on the stability factors are as follows: Intersection rate: 0.9; mutation percent: 0.3; mutation rate: 0.02; selection mechanism: roulette wheel.

Given that the two presented factors provided for different combinations of parameters act in the same direction and have the same results levels of selected parameters are as follows: Intersection rate: 0.9; mutation percent: 0.3; mutation rate: 0.02; selection mechanism: roulette wheel.

In addition to setting of the parameters that were examined above to implement the algorithm the number of iterations of the algorithm and used population size should be set. Increase in the number of iterations of the algorithm allows the model to have ample opportunity to solve the problem and larger number in this parameters will lead to better results. But it should be noted that by selecting larger amounts of iteration computational time will increases. For proposed GA algorithm, a number of 200 irritations is considered and the algorithm will stop at 200 irritations. Also with increase in population size algorithm will search for more points in the answer space and the quality and answers' dispersion will increases. As the result for proposed algorithm population size is considered 30. After setting the parameters of the model and solving it with GA, according to output results of MATLAB optimum number of suite rooms will be 64 units, one-bedroom and two-bedroom apartments respectively 37 and 32 units. Also to compare the results of two exact and meta-heuristic methods obtained from the MATLAB program, the problem is solved in different scales. The results of which are summarized in ***Table 4*** below.

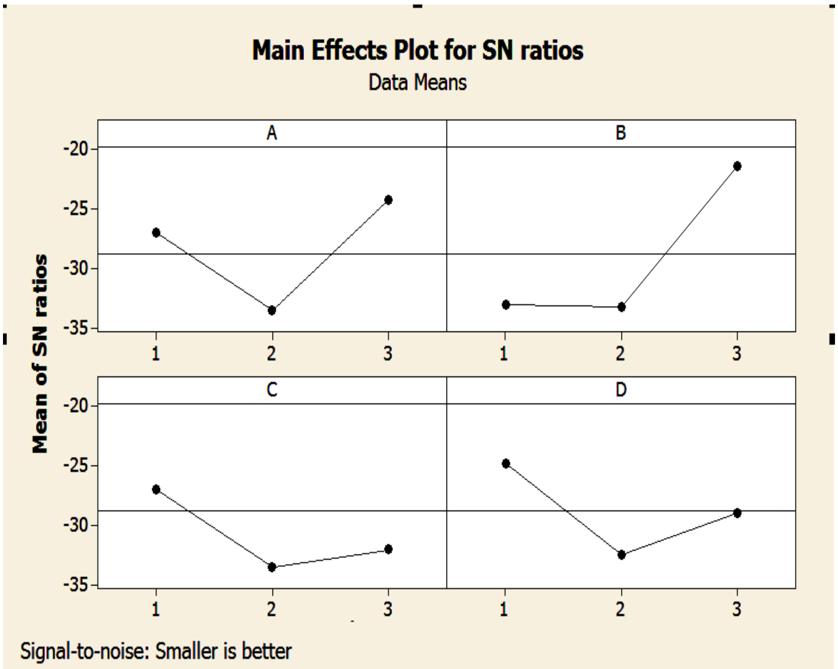

Fig. 12. *Comparison of the answers stability.*

Table 4. *Comparison of the solutions to the problem of hotel capacity.*

Global Solver (lingo)				**Proposed GA**		
	max k_j	*Objective value*	*Computational time*	*Objective value*	*Computational time*	*RPD*
	10	*736*	*42*	*736*	*81*	*0%*
Small	*15*	*1450*	*113*	*1450*	*84*	*0%*
	20	*288*	*251*	*295*	*92*	*2%*
	30	*459*	*484*	*475*	*99*	*3%*
Medium	*40*	*190*	*753*	*199*	*102*	*5%*
	50	*1093*	*1152*	*1140*	*108*	*4%*
	100	-	-	*894*	*188*	-
Large	*500*	-	-	*570*	*223*	-
	1000	-	-	*1230*	*302*	-

6. Concluding Remarks and Future Research Directions

In this study, a Knapsack model based on the queuing theory was proposed for determining the optimal number of hotel rooms as an optimization problem. In the proposed model, first, hotel's reception system was simulated applying the principles of queuing theory. Then, a Knapsack model was developed to determine the optimal capacity of the hotel with defining a cost function and considering the financial and space limitations constraints. In the next stage, according to the complexity of the Knapsack model, a GA approach was utilized for solving both large-scale and small-scale problems. It should be noted that the GA parameters were set using Taguchi method. Unlike the previous models that can be used for a specific hypothetical condition, using queuing theory with various models enables the proposed model to adapt to different real conditions. There are many studies utilizing queuing models which we can easily utilize considering different conditions.

For future studies, it is recommended that the model presented in this article was expanded using non-Markov queuing models with some general distribution functions (such as the G/G/1) for conditions where guests arrival rates at the hotel or stay time of guests have distributions other than Poisson and Exponential distributions. Moreover, other meta-heuristic solutions could be applied to solving the model and the results are compared with the findings of this study.

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