Journal of Universal Computer Science, vol. 28, no. 4 (2022), 396-413
submitted: 12/8/2021, accepted: 4/2/2022, appeared: 28/4/2022

A Late Acceptance Hyper-Heuristic Approach for the Optimization Problem of Distributing Pilgrims over Mina Tents

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Abstract: About three million Muslims are traveling annually to Makkah in Saudi Arabia to perform the rituals of Hajj (i.e. the pilgrimage), the fifth pillar of Islam. It requires the pilgrims to move to several holy sites while performing the Hajj ritual, including Mina, Arafat, and Muzdalifah sites. However, pilgrims spend most of their time in prepared tent-camps at the Mina site during the days of Hajj. Among the challenges that the organizers face in the Hajj is the distribution of pilgrims over the camps of Mina while considering a range of constraints, which is considered a real-world optimization problem. This paper introduces a hyper-heuristic approach to optimize the distribution process of pilgrims over Mina tent-camps in an efficient manner, named the hyper-heuristic Mina tents distribution algorithm (HyMTDA). The proposed algorithm, iteratively, selects one heuristic among four predefined low-level heuristics to produce a new solution; thereafter the late move acceptance strategy is applied as a judgment to accept or reject the new solution. The performed simulations show that the proposed HyMTDA can effectively explore the search space and avoid falling into local minima during the iterations process. Moreover, comparisons show that HyMTDA outperforms other heuristic algorithms in the literature in terms of solution quality and convergence rate.

Keywords: Hajj rituals, Mina tents, distribution problem, optimization techniques, hyper-heuristic algorithm
Categories: I.0, I.2, I.2.1, I.2.8, I.m, J.m
DOI: 10.3897/jucs.72900

1 Introduction

Every year, around three million Muslims travel to Makkah, Saudi Arabia, to perform Hajj during the lunar month of Dhu al-Hijjah, from the 8th to the 13th. Pilgrims spend the majority of their Hajj nights in Mina, one of Islam's holiest sites, which is considered the largest tent city in the world as it includes about 160,000 tents built for pilgrim housing. The number of pilgrims in the 2018 Hajj season was 2,371,675 pilgrims [GAS, 2021], whereas the available area to accommodate pilgrims in Mina is about 2,652,752 square meters [Edrees, 2013]. Many initiatives to expand Mina's capacity have been proposed, studied, and developed, and there is a chance that the capacity dedicated to accommodating a larger number of pilgrims will be increased in the future.

Due to Mina's capacity limitations, the best distribution of pilgrim groups to the camp-tents is one of the challenges that organizers of pilgrims housing encounter every year, especially for those groups with a large number of pilgrims. The procedure of assigning pilgrims to a limited number of tent-camps intended for housing pilgrims is a real-world optimization problem that requires an advanced algorithm capable of providing high-quality solutions [Shambour & Khan, 2019].

In the current optimization problem, the data set includes 610 groups of pilgrims, each with a random number of pilgrims ranging from 200 to 5,000, which should be assigned to 1,112 tent-camps of various sizes ranging from 200 to 5,000 square meters [Dataset, 2022]. During the assignment process, many factors must be considered, including the number of pilgrims in each group, tent-camp capacity, reserved classes, train usage, and location of tent-camp. This problem belongs to the category of resource allocation problems, in which the goal is to determine the best way to allocate a set amount of resources to activities while minimizing the cost incurred by the allocation [Katoh N. & Ibaraki, 1998].

The complexity of such a resource allocation problem can be gauged by the fact that it is classified as an NP-hard problem that cannot be solved in polynomial time [Yilmaz & Başçiftçi, 2021; Zhang W., 2002]. Solving such problems needs the use of an optimization method capable of exploring many optima in their search space.

A hyper-heuristic method is one of the most popular methods that has been widely applied to tackle various optimization problems in the combinatorial optimization field, such as routing problems [Olgun et.al., 2021; Zhao et al., 2021], timetabling problems [Kheiri, et al., 2021; Kheiri & Keedwell, 2017; Shambour et al., 2013; Shambour & Khan, 2022], space allocation problems [Czerniachowska & Marcin, 2021; Vincent et al., 2020], engineering design problems [Oteiza et al., 2021], etc. Moreover, a hyper-heuristic method is distinguished from other heuristic methods in that it has the ability to explore the search space without requiring more information about the search domain [Burke et al., 2003; Abd Elaziz et al., 2020].

This paper investigates the use of a hyper-heuristic method to optimize the distribution process of pilgrim groups over the available space of Mina's tent-camps, named a hyper-heuristic Mina tents distribution algorithm (HyMTDA). The algorithm is designed in such a way that it can use the available resources very efficiently while respecting the hard and soft constraints. Two stages are involved during search iterations of hyper-heuristic single-point based search framework, heuristic selection and move acceptance [Ozcan et al., 2008]. In the first stage, the HyMTDA employs one of four low-level heuristics to produce a new solution (i.e. heuristic selection); whereas in the second stage, the late acceptance technique is applied to accept or ignore the produced solution (i.e. move acceptance). Furthermore, multiple simulations and comparisons with other methods from the literature were performed to verify the efficiency of the developed algorithm in terms of objective function values.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature to the work of this paper. Section 3 explains the problem description. Hyper-heuristic approach for Mina camps distribution and simulation results are given in Section 4 and Section 5, respectively. Finally, Section 6 provides the conclusions and directions for further research.

2 Related Works

In recent years, there have been several attempts to study and address a wide range of Hajj applications [Shambour & Gutub, 2021; Shambour & Dhubaib, 2022; Shambour, 2021]. However, few research studies have addressed the problem of optimizing the distribution process of a large number of pilgrims to a limited number of tent-camps. This optimization problem has multiple resources that need to be utilized efficiently while satisfying a set of hard and soft constraints (e.g. predefined tents must not be violated, every pilgrim group must be assigned once, and two pilgrim groups cannot be allocated to the same tent). The current problem is related to resource allocation problems in that it attempts to monitor the optimal allocation of a number of specific resources to activities while reducing the distribution process cost [Katoh et al., 2013].

[Shambour et al., 2017] presented a framework for efficiently distributing tent-camps in Mina area. The proposed framework is based on employing artificial intelligence methods to extract the spatial data of Mina area. Thereafter, the extracted data is prepared to be used for further analysis, as well as conducting experiments using heuristic methods. According to the recommendations, the proposed framework aids in the utilization of the maximum capacity of available resources, resulting in an increase in the Mina area's capacity. Later, [Shambour & Khan, 2019] developed a heuristic-based approach to distributing pilgrims over Mina camps. The algorithm begins by iteratively offering all available and appropriate tent-camps in Mina for a randomly selected pilgrims' group. Then, one of the seven assignment methods is chosen to determine the best suitable tent-camp for the taken pilgrims' group. In terms of space allocation, the proposed algorithm performed well, with about 80 percent of pilgrims being assigned to more than 76.2 percent of the total housing space in the Mina area.

The previous studies mentioned above are the only ones that look at the use of heuristic algorithms to optimize pilgrim distribution over Mina's tent-camps [Shambour & Gutub, 2021]. However, various approaches are applied to solve a variety of similar optimization problems, which are roughly divided into four categories, sequential methods, cluster methods, constraint-based methods, and meta-heuristic methods [Carter et al., 1996; Carter et al., 1998; Burke, 2002]. Researchers from several fields, such as computational intelligence [Deveci et al., 2018; Demirel et al., 2017], have recently adopted heuristics, meta-heuristics, and hyper-heuristics as preferred methods, particularly for problems requiring a high amount of computational resources, as they can produce good quality solutions in a reasonable amount of time when compared to other traditional methods.

The heuristics and meta-heuristics frameworks are classically working on the problem directly and often know the domain, whereas hyper-heuristic framework runs at a higher abstraction level which is often working without knowledge about the domain [Burke et al., 2003]. The term "hyper-heuristic" has been defined in the literature by several authors, such as that by Cowling et al. [Cowling et al., 2001] who defined it as "a heuristic to choose heuristics". Another definition given by Drake et al. [Drake et al., 2019] is "a high-level automated search methodology which explores a search space of low-level heuristics or heuristic components, to solve computationally hard problems". Burke et al. [Drake et al., 2019] defined it as "an automated methodology for selecting or generating heuristics to solve hard computational problems". Generally, hyper-heuristic approaches have become a growing trend over the past few years due to their remarkable efficiency in many applications of operation research and computer science fields. Following are some research discussions related to the use of hyper-heuristic in several areas of optimization fields.

Steenson et al. [Steenson et al., 2021] applied a multistage hyper-heuristic mechanism on three classes of education timetabling problems (examination timetabling, post-enrolment-based timetabling, and curriculum-based course timetabling). The authors identified six successive stages of low-level heuristics consisting of hill climbing, great deluge, and simulated annealing. Thereafter, the performance of each successive stage was tracked and recorded to observe the best sequence of low-level heuristics. In another education timetabling problem, Kheiri et al. (2016) and Kheiri & Keedwell (2017) applied a hyper-heuristic approach to solving the high school timetabling problem. The authors explored the performance of the proposed approach on both random-based selection and sequencing-based selection of low-level heuristics. Leng et al., (2019) presented a multi-objective hyper-heuristic method for location-routing problem considering a town wherein goods are needed to be picked up from stores and delivered to clients.

In another work, Chen et al. (2016) investigated the performance of several hyper-heuristic methods on the periodic vehicle routing problem. The authors applied five heuristic selection methods. The experimental results proved an improvement in the performance of hyper-heuristic techniques when a dedicated local search phase was included. Moreover, hyper-heuristic has been applied to solve numerous resource allocation problems such as the container allocation problem [Tan et al., 2019], the fog allocation problem [Kabirzadeh et al., 2017], and tasks allocation [Pour et al., 2018; Babić et al., 2018]. Furthermore, comprehensive surveys of hyper-heuristic and their applications could be found in [Ozcan et al., 2008; Drake et al., 2019; Burke et al., 2013].

This section discussed the paucity of research studies that have addressed the current optimization problem, as well as the optimization techniques that are applied to solve a variety of optimization problems from diverse application fields. The main objective of this research work is to employ an effective technique for efficiently distributing pilgrims to tent-camps while making use of all the available allocated space. By achieving this objective, more pilgrims will be able to accommodate in tent-camps, more equity in pilgrim accommodation for different groups of pilgrims, and more information and alternative scenarios that decision-makers will have about how to accommodate pilgrims to tent-camps in sufficient time before the Hajj season begins.

3 Problem Modelling and Description

Our distribution problem is concerned with distributing all pilgrim groups over different tent-camps while respecting a set of constraints. The specifications of pilgrim groups and accommodated tents used in this paper are adopted from a previous work presented in [Shambour & Khan, 2019]. The descriptions of problem attributes and constraints are explained in the following subsections.

3.1 Problem Attributes

All pilgrim groups (PGs) are classified, according to their home countries, into six country groups (CGs). Figure 1 illustrates the defined CGs as well as the number of pilgrims in every CG for the 2018 Hajj season. Moreover, each CG has several PGs, and each PG comprises several pilgrims who share the same services and host features such as train usage, tent-camp location, etc.

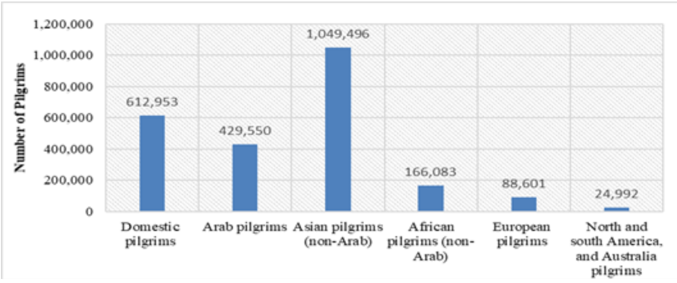

Figure 1: Number of pilgrims for the classified CGs in the 2018 Hajj season

Furthermore, the number of PGs for all CGs was set to 610 PGs, each containing a random number of pilgrims ranging between 200 to 5,000. An example of the assignment process for European PGs is presented in Table 1.

European PG	Number of Pilgrims
PG*1*	1,021
PG*2*	1,158
PG*3*	1,053
.	.
PG*25*	4,354
Total	**88,601**

Table 1: An example for assigning pilgrims to European PGs

Consequently, the key attributes of the PG data input are defined as shown in Table 2.

	Attribute Name	Abbreviation
Att.1	ID	PG_j
Att.2	Class	PG_{j_c}
Att.3	CG ID	PG_{j_g}
Att.4	Inside/ outside Mina	PG_{j_m}
Att.5	Train usability	PG_{j_r}
Att.6	Number of Pilgrims	PG_{j_n}
Att.7	MinSpace	PG_{j_u}
Att.8	MaxSpace	PG_{j_v}

Table 2: Attributes of PG

Where "*ID*" denotes the identification and unique number assigned for every PG, "*Class*" represents the class area of tents used to locate PGs to tent-camps of a certain class area$(C_1, C_2, \dots, C_7)$, "*Inside/outside Mina*" refers to the area in which a certain tent-camp is located, "*Train usability*" indicates the ability or inability of pilgrims to use the train, and "*MinSpace*" and "*MaxSpace*" represent the minimum and maximum space per PG, respectively. Moreover, the main attributes of the tent-camp data input are defined as given in Table 3.

	Att1	Att2	Att3	Att4	Att5	Att6
Attribute Name	Tent ID	Block ID	Class	Inside/outside Mina	Train usability	Space
Abbreviation	T_i	T_{i_b}	T_{i_c}	T_{i_m}	T_{i_r}	T_{i_s}

Table 3: Attributes of Tent-camp (T)

Where "*Tent ID*" refers to the identification and unique number assigned for every tent camp, "*Block ID*" is the identification number for a block area to which the tent-camp belongs, "*Class*" and "*Inside/ outside Mina*" are similar to those in PG attributes, "*Train usability*" indicates the tent-camps identified to accommodate pilgrims who need to use the train, and "*Space*" denotes the available space designated for the accommodation of pilgrims. The number of blocks in tent-camps is 230 blocks, each of which has a random number of tent-camps ranging between 1 and 10. Furthermore, the size of tent-camps ranged from 200 to 5,000 square meters. Table 4 illustrates the summary of data attributes.

Attribute Name	**Value**	**Unit**
Number of pilgrims	2,371,675	Pilgrim
Number of PGs	610	PGs
Housing space in Mina	2,652,752	Square meter
Number of Tent-Camps	1,112	tent-camps
Domestic pilgrims	612,953	Pilgrim
	203	PG
Arab pilgrims	429,550	Pilgrim
	40	PG
Asian pilgrims (non-Arab)	1,049,496	Pilgrim
	297	PG
African pilgrims (non-Arab)	166,083	Pilgrim
	39	PG
European pilgrims	88,601	Pilgrim
	19	PG
North and south American, and Australian pilgrims	24,992	Pilgrim
	12	PG
Class area C_1	144	Tent-camp
	50	Block
Class area C_2	177	Tent-camp
	36	Block
	112	Tent-camp

Class area C_3	22	Block
Class area C_4	81	Tent-camp
	26	Block
Class area C_5	199	Tent-camp
	47	Block
Class area C_6	228	Tent-camp
	44	Block
Class area C_7	171	Tent-camp
	27	Block

Table 4: Data attributes

3.2 Problem Formulation

This study defines nine constraints that need to be satisfied in the final solution to observe the optimal solution. These constraints are classified into four hard constraints (*H1, H2..., H4*) that should not be violated, and five soft constraints (*S1, S2, ..., S5*) that are to be satisfied as much as possible. The mathematical representation of the problem is provided as follows [Shambour & Khan, 2019]:

Assignment (*A*) is a function of resources (*PG, T*), such that the problem constraints can be mathematically formulated as given in Table 5 and Table 6.

Constraint ID	**Formulation of Hard Constraints**
H1	Predefined tents must not be violated. $A_{PG_j}^{T_v} = \emptyset \quad where\ T_v\ is\ a\ Predefined\ tent, \forall j \in PG$
H2	Every pilgrim group must be assigned once. $A_{PG}^{T} = A_{PG_j}^{T_i} \quad \forall i \in T, j \in PG$
H3	Two pilgrim groups cannot be allocated to the same tent. $A_{PG_j}^{T_i} \neq A_{PG_k}^{T_i} \quad j \neq k, \forall i \in T, \forall j \in PG, \forall k \in PG$
H4	The space available for each tent-camp should be suitable for the number of assigned pilgrims. $A_{PG_{j_s}}^{T_i} \geq A_{PG_{j_u}}^{T_i} \quad where\ PG_{j_s}\ is\ the\ allocated\ space\ for\ PG_j, \forall i \in T, \forall j \in PG$

Table 5: Mathematical formulation of hard constraints

Constraint ID	Formulation of Soft Constraints
S1	A group of pilgrims who need to use the train should be assigned to tents near the train station. $A_{PG_j}^{T_i} = A_{PG_{j_{r2}}}^{T_{i_{r1}}}$ $where\ r1, r2 \in \{0 = false, 1 = true\},$ $\forall i \in T, \forall j \in PG$
S2	Pilgrim group should be assigned to a tent-camp that belongs to the pilgrims reserved class. $A_{PG_j}^{T_i} = A_{PG_{j_{c_n}}}^{T_{i_{c_m}}}$ $n = m, \forall i \in T, \forall j \in PG$
S3	The accommodation space for a tent-camp should be fit for the assigned pilgrim group. $A_{PG_j}^{T_i} = A_{PG_{j_q}}^{T_{i_s}}$ $where\ PG_{j_q} is\ the\ allocated\ space\ for\ PG_j,$ $T_{i_s} - PG_{j_q} \cong 0,\ \ \forall j \in PG, i \in T$
S4	Pilgrim groups that are similar in terms of a country group should be located in tents next to each other. (current tent's block number – any adjacent tent's block number <=1). $A_{PG_{j_g}}^{T_{i_b}} = A_{PG_{l_g}}^{T_{k_b}}$ $i \neq k, j \neq l, \forall i \in T, \forall j \in PG, l \in PG$
S5	A pilgrim group should be assigned to a tent/tents belonging to at most two adjacent tents blocks. $A_{PG_j}^{T_{i_{b_m}}} = A_{PG_j}^{T_{i_{b_n}}} \left\| T_{i_{b_m}} - T_{i_{b_n}} \right\| = \{0,1\}, n = m, \forall i \in T, \forall j \in PG$

Table 6: Mathematical formulation of soft constraints

The weight (cost) of each constraint violation is given in the following table. Note that these weights are determined according to their importance to the problem, as far as the constraint required to be fulfilled in the solution, the violation cost becomes higher. A valid solution is obtained if it satisfies all the hard constraints of the problem.

Constraint	H1	H2	H3	H4	S1	S2	S3	S4	S5
Weight	100,000	1,000	1,000	1,000	10	10	0.1	10	10

Table 7: Weights of constraint violations

This problem is a minimization problem where the goal is to obtain the optimal solution by distributing all pilgrim groups on the available accommodation tents in the Mina area while satisfying all hard and soft constraints. Accordingly, the objective function is defined as minimizing the costs of violating problem constraints that appear in the final solution, which can be declared as follows:

$$minimize\ (\sum_{H=1}^{4} W_H\ \ Vtimes_H\ (Sol) + \sum_{S=1}^{5} W_S\ \ Vtimes_S(Sol)\ )$$

Where W denotes the weight of constraint, $Vtimes$ refers to the number of times a constraint is violated in the produced solution, and Sol refers to the solution representation.

4 Proposed Approach

A hyper-heuristic approach, called hyper-heuristic Mina tents distribution algorithm (HyMTDA), is applied to optimize the distribution of pilgrims on the definite number of tent-camps in Mina. Figure 2 provides a flowchart for the proposed approach including its main steps. Detailed descriptions of each step are offered in the following subsections.

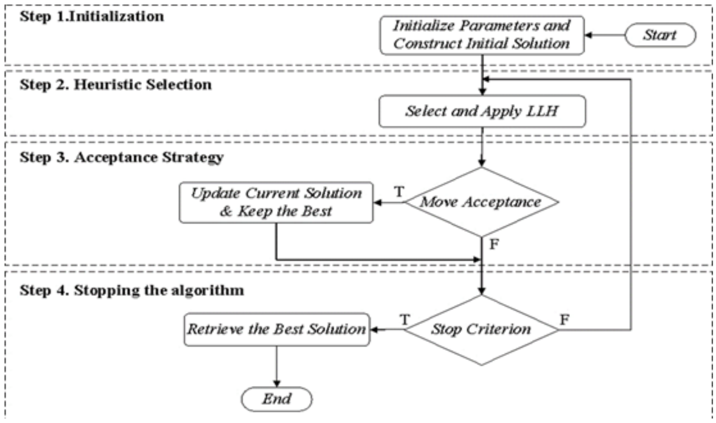

Figure 2: Flowchart of the proposed HyMTDA

4.1 Initialization

Two initialization procedures are included in this step, initializing algorithm and problem parameters, and constructing an initial solution.

First, the proposed HyMTDA and problem parameters are defined, including the maximum iteration number (MaxItr), the number of PGs in all CG, number of pilgrims in every PG, the PG's class, the number of tent-camps in every block, the space and location of all tent-camps, and usability of the train.

Then, HyMTDA applies different allocation schemes to build an initial solution by assigning all pilgrim groups to suitable tent-camps as much as possible. The algorithm picks the best solution out of ten initial solutions generated, in terms of objective function value, and passes it to the next step. The descriptions of the applied schemes are presented as follows [Shambour & Khan, 2019]:

- BlockFit (BF): designed to allocate a group of pilgrims to all tent-camps of one block.
- TwoBlockFit_1 (TBF1): designed to allocate a group of pilgrims to all tent-camps of two adjacent blocks.

- Part-blockFit (PF): designed to allocate a group of pilgrims to some tent-camps of one block.
- TwoBlockFit_2 (TBF2): designed to allocate a group of pilgrims into two adjacent blocks, such that all tent-camps of the first block and some tent-camps of the second block are taken.
- TwoBlockFit_3 (TBF3): designed to allocate a group of pilgrims into two adjacent blocks, such that some tent-camps of the first and second blocks are taken.
- ElasticBlockFit (EBF): designed to allocate a group of pilgrims to all tent-camps of one block with leaving some space unallocated.
- ElasticPart-blockFit (EPF): designed to allocate a group of pilgrims to some tent-camps of one block with leaving some space unallocated.

Figure 3 shows some examples of the mechanisms used by allocation schemes to assign a PG to one or more block areas (i.e. A, B, C, or D). It should be noted that the shaded shapes in the figure represent a reserved area of Mina blocks.

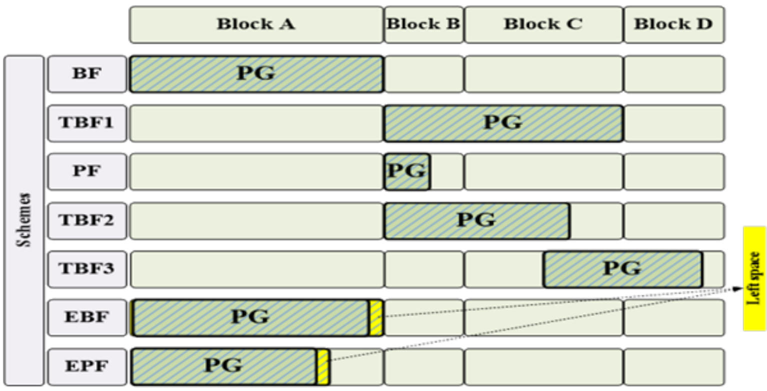

Figure 3: Examples of allocation schemes

4.2 Heuristic Selection

The proposed HyMTDA randomly selects and applies one of four defined low-level heuristics (LLH) that attempt to optimize the solution quality. The defined LLHs are:

- Move heuristic (LLH1): This heuristic randomly selects an allocated PG and checks whether it can be assigned to another available tent-camp or not. If it can be assigned, the previous tent-camp is set to be available and the current tent-camp becomes unavailable.
- Assign heuristic (LLH2): This heuristic randomly selects an unallocated PG and tries to allocate it to a suitable tent-camp using one of a randomly selected allocation scheme mentioned earlier (e.g. BF, TBF1, etc.).
- Swap heuristic (LLH3): This heuristic randomly selects two allocated PGs and tries to swap their tent-camps.
- Replace heuristic (LLH4): This heuristic randomly selects an allocated PG and replaces it with an unallocated PG.

4.3 Acceptance Strategy

The move acceptance strategy used in this paper is based on a local search strategy proposed by Burke and Bykov [Burke & Bykov, 2017] called late acceptance hill-climbing (LAHC). The idea of using LAHC is to give the algorithm more chances to effectively explore the solution space and avoid falling into the local minimums where non-improving movements could be accepted while conducting the search process. More details about the algorithm can be found in [Burke & Bykov, 2017].

4.4 Stopping the Algorithm

The best solution in terms of the objective function will be offered when one of two conditions is met. First, all groups of pilgrims are assigned to tent-camps. Second, the maximum iteration number is reached. Algorithm 1 shows the basic pseudocode of the proposed algorithm.

Algorithm 1: Pseudocode of the proposed HyMTDA

Step1: Initialization of the HyMTDA and problem-specific parameters, and construct initial solutions
    [MaxItr, CG, PG, Class, Block, Space, Location, Train usability, etc]
    Generate *n* initial solutions $S_i = (S_1, S_2, \dots, S_n)$
    Select the best initial solution $S = S_{best}, S_{best} \in (S_1, S_2, \dots, S_n)$
    Specify the history length (l_h) of a list K
    Set initial costs to history list elements// $f(K_j) = C, j \in (0, l_h - 1)$
    Set Itr=0

Step2: Heuristic Selection
    S^*= SelectAppLLH(LLH_h, S) // $h = \{1,2,3,4\}$

Step3: Acceptance Strategy
  Find the cost $f(S^*)$
  Find the n^{th} location of a list K// $n = Itr \bmod l_h$
  If $f(S^*) < f(S)$ or $f(S^*) \le f(K_n)$
    $f(K_n) = f(S^*)$
    $S = S^*$
  End If

Step4: Stopping the Algorithm
  If termination conditions apply
    Stop the algorithm's iterations
  Else
    Itr=Itr+1 and repeat steps 2,3, and 4.
  End If

5 Experimental Results

This section presents the evaluation of the proposed HyMTDA and compares it with the performance of other algorithm schemes proposed in the literature, in terms of the objective function value.

5.1 Experimental design

The proposed HyMTDA was evaluated using the parameter setting listed in Table 8. Recall that the MinSpace and MaxSpace parameters represent the minimum and maximum allowable space for each PG, whereas the Flexibility Rate parameter provides an extra space rate to assign a PG to a tent-camp; In other words, the maximum allowable allocation area can increase up to 1.3 m^2. MaxItr refers to a maximum number of iterations in every single run.

Parameter	MinSpace (m^2)	MaxSpace (m^2)	Flexibility Rate (m^2)	MaxITr
Value	1.0	1.2	0.1	1×5^6

Table 8: Experimental Settings

The simulation was coded in Matlab version 2014a programming language and ran on Windows 10 with Intel Xeon(R) CPU E3-1240@3.4 GHz processor with 32 GB of RAM.

5.2 Effect of history length (l_h) of LAHC

Six experiments were performed to observe the best setting for l_h parameter among the values: 1, 100, 500, 1000, 5000, and 10000. Each experiment runs 30 times, each run constructs ten initial solutions, and the best solution, in terms of objective function value, will only be considered for further investigation. The statistical results of the 30 runs for each experiment are given in Table 9, whereas Figure 4 shows the convergence performance of HyMTDA on different values of l_h parameter.

	l_h=1	l_h=100	l_h=500	l_h=1000	l_h=5000	l_h=10,000
Mean	190,763.3	178,883.2	179,509.1	178,265.2	179,350.7	**176,936.7**
Std	59,59.4	7,783.87	6,321.67	7,488.66	6,062.19	7,183.09
Min	178,011	163,993	167,528	161,650	167,935	**159,577**
Max	201,647	194,193	193,725	194,453	193,045	189,730

Table 9: Statistical results of HyMTDA performance on different values of l_h

Since the problem is stated as a minimization problem, it can be observed from Table 9 and Figure 4 that the best performance of the proposed algorithm, in terms of fitness value and convergence rate, was found when the value of l_h parameter was equal to 10,000, where the best mean and minimum results (shown in bold) of 30 runs were 176,936.7 and 159,577, respectively. Consequently, the performance results when l_h is equal to 10,000 is only considered for the subsequent performance evaluations of HyMTDA compared to other competitive algorithm schemes.

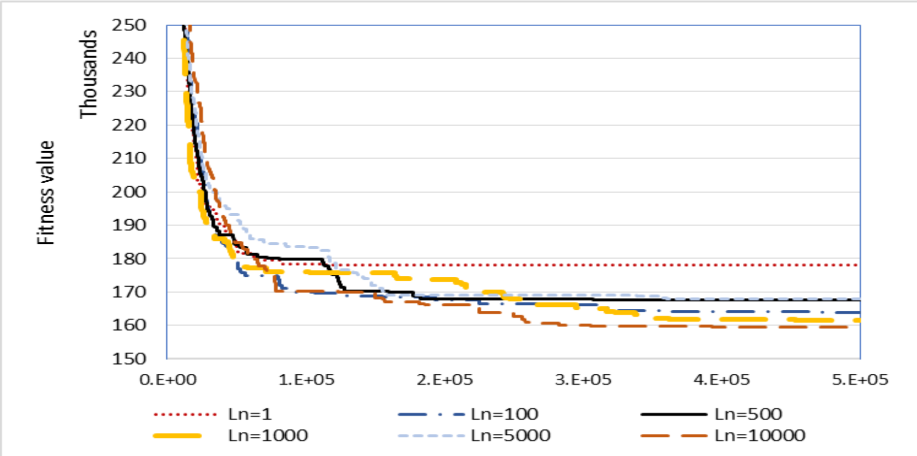

Figure 4: Convergence rate of HyMTDA on different values of l_h parameters

5.3 Performance Comparison and Discussion

The performance of the proposed HyMTDA and eight other algorithm schemes were examined using the same parameter settings mentioned earlier. The eight compared algorithms include BF, TBF1, PF, TBF2, TBF3, EBF, EPF, and MTDA algorithms. Table 10 shows the analysis of fitness results, across 30 runs, for each compared algorithm, whereas Figure 5 provides a comparison of their best convergence performance.

	Mean	Std.	Min	Max
HyMTDA	**176,936.7**	7,183.1	**159,577**	189,730
MTDA	187,904.5	6,897.4	171,618	201,954
BF	522,706.2	1,720.6	519,485	527,120
TBF1	537,963.2	3,429.0	529,131	543,258
PF	210,176	5,559.2	198,590	220,465
TBF2	511,092.5	3,269.6	503,862	517,141
TBF3	430,106.9	7,784.4	411,859	446,826
EBF	513,274.9	1,847.6	509,208	516,195
EPF	188,134.6	7,026.9	174,522	204,589

Table 10: Statistical results of compared algorithms

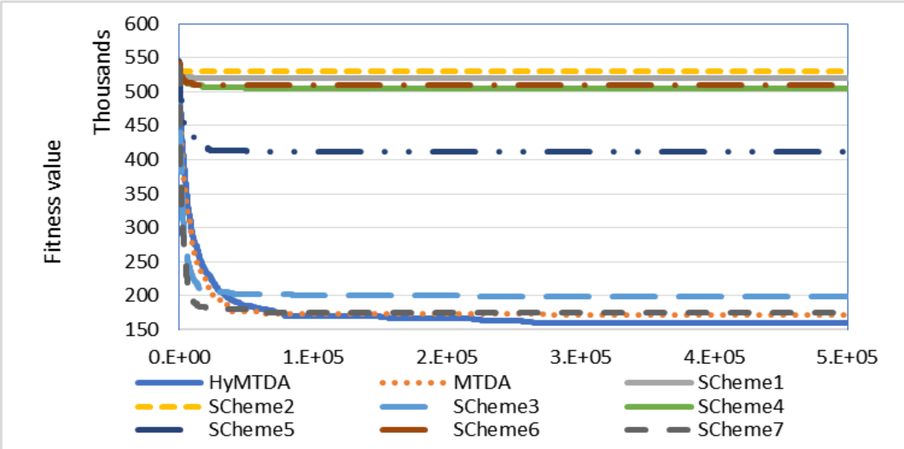

Figure 5: Convergence curves of the compared algorithms

Results verify that the performance of the proposed HyMTDA is better compared to other algorithms as HyMTDA achieves the best mean result (shown in bold) and the best convergence performance among other algorithms. Furthermore, the proposed HyMTDA outperforms the second best algorithm (MTDA) by 6.2% in terms of the objective function value. Also, the EPF and PF schemes performed well, ranking third and fourth-best algorithm schemes, respectively, with a considerable difference from the rest of the algorithm schemes.

Furthermore, ANOVA statistical test tool is used to check whether there is a significant difference between the results achieved by the compared algorithms or not. The null hypothesis states that the mean values of all compared algorithms are the same such that:

- $\boldsymbol{h_0}$: μ1 = μ2 = μ3 = μ4= μ5 = μ6 = μ7= μ8 = μ9, where μ is the mean.
- $\boldsymbol{h_1}$: Not all means are equal

Table 11 displays the p-value and F-score values of the ANOVA analysis results obtained from the experimental study. The p-value is smaller than the significance level (5%), indicating that significant differences between the means existed. As a result, the null hypothesis h_0 is rejected, and the alternative hypothesis h_1 is accepted. In other words, with a 95 % confidence level (α = 0.05), there is a significant difference between the compared algorithms.

	Sum of Squares	**Degree of Freedom**	**Mean Square**	***F-score***	***P-value***	***F crit***
Between Groups	6.73E+12	8	8.41E+11	28159.3	0.0	1.97
Within Groups	7.8E+09	261	29874572.3			
Total	6.74E+12	269				

Table 11: ANOVA descriptive statistics

6 Conclusion and future work

Distributing a large number of pilgrims to a limited number of camp-tents, while satisfying a set of hard and soft constraints, is a real-world optimization problem defined as an NP-hard problem. In this paper, a hyper-heuristic with a late acceptance hill-climbing algorithm, called HyMTDA, is used to maximize the usage of the limited area of tent-camps in Mina by making the best use of available resources.

The proposed HyMTDA includes two main phases: heuristic selection and move acceptance phases. In the first phase, four low-level heuristics named Assign, Move, Swap, and Replace were employed on a group of pilgrims in an attempt to increase the quality of the solution. In the second phase, the late acceptance technique is used to determine if the current solution should be accepted or rejected.

The best performance of HyMTDA, which is used in the comparisons, was tested using various settings of history length (l_h) of LAHC. In addition, several experiments and comparisons with other algorithms from the literature were carried out to ensure the efficiency of the proposed algorithm, in terms of objective function value and convergence performance. The experimental results revealed that the performance of the proposed HyMTDA outperforms existing algorithms in the literature, including BlockFit, TwoBlockFit_1, Part-blockFit, TwoBlockFit_2, TwoBlockFit_3, ElasticBlockFit, ElasticPart-blockFit, and MTDA algorithm schemes Moreover, when compared to the second-ranked performance algorithm (MTDA), the proposed algorithm (HyMTDA) outperforms the second-ranked algorithm (MTDA) by 6.2 percent, in terms of the objective function value.

Finally, even though the proposed algorithm outperformed other algorithms, the cost of the fitness function evaluation remains high and significant. This requires improving the performance of HyMTDA by investigating other techniques that may improve the quality of the solution produced. Future work will concentrate on enhancing the HyMTDA algorithm's performance by experimenting with various selection and move acceptance strategies, combining with other heuristic algorithms, and conducting a sensitivity analysis for the algorithm’s parameters.

Acknowledgments

The authors would like to thank the Deanship of Scientific Research at Umm Al-Qura University for supporting this work by Grant Code: (22UQU4361183DSR01).

References

[Abd Elaziz et al., 2020] Abd Elaziz, Mohamed, Ahmed A. Ewees, and Diego Oliva. "Hyper-heuristic method for multilevel thresholding image segmentation." Expert Systems with Applications 146 (2020): 113201.

[Babić et al., 2018] Babić, A., Mišković, N., & Vukić, Z. Heuristics pool for hyper-heuristic selection during task allocation in a heterogeneous swarm of marine robots. IFAC-PapersOnLine, 51(29), (2018). 412-417. https://doi.org/10.1016/j.ifacol.2018.09.452

[Burke, 2002] Burke E.K., "Recent research directions in automated timetabling," European Journal of operational Research 140, (2002). 266-280, https://doi.org/10.1016/S0377-2217(02)00069-3.

[Burke et al., 2003] Burke E., Kendall G., Newall J., Hart E., Ross P., Schulenburg S. (2003) Hyper-Heuristics: An Emerging Direction in Modern Search Technology. In: Glover F., Kochenberger G.A. (eds) Handbook of Metaheuristics. International Series in Operations Research & Management Science, vol 57. Springer, Boston, MA. https://doi.org/10.1007/0-306-48056-5_16

[Burke et al., 2010] Burke E.K., Hyde M., Kendall G., Ochoa G., Özcan E., Woodward J.R. A Classification of Hyper-heuristic Approaches. In: Gendreau M., Potvin JY. (eds) Handbook of Metaheuristics. International Series in Operations Research & Management Science, vol 146. Springer, Boston, MA. (2010). https://doi.org/10.1007/978-1-4419-1665-5_15

[Burke et al., 2013] Burke Edmund K, Gendreau Michel, Hyde Matthew, Kendall Graham, Ochoa Gabriela, Özcan Ender & Qu Rong. Hyper-heuristics: a survey of the state of the art, Journal of the Operational Research Society, (2013). 64:12, 1695-1724. https://doi.org/10.1057/jors.2013.71

[Burke & Bykov, 2017] Burke Edmund and Bykov Yuri. The late acceptance Hill-Climbing heuristic. European Journal of Operational Research. (2017). 258(1), 70-78. https://doi.org/10.1016/j.ejor.2016.07.012

[Carter et al., 1996] Carter, M.W., Laporte, G., 1996. Recent developments in practical examination timetabling. In: Burke and Ross, (1996), pp. 3–21. https://doi.org/10.1007/3-540-61794-9_49

[Carter et al., 1998] Carter, M.W., Laporte, G., 1998. Recent developments in practical course timetabling. In: Burke and Carter, (1998), pp. 3–19. https://doi.org/10.1007/BFb0055878

[Chen et al., 2016] Chen, Y., Mourdjis, P., Polack, F., Cowling, P., & Remde, S. Evaluating Hyperheuristics and Local Search Operators for Periodic Routing Problems. Lecture Notes in Computer Science, (2016). 104–120. doi:10.1007/978-3-319-30698-8_8

[Cowling et al., 2001] Cowling P, Kendall G, Soubeiga E. A hyperheuristic approach for scheduling a sales summit. In: PATAT 2000. LNCS 2079. Springer, Berlin, (2001). 176–190, https://doi.org/10.1007/3-540-44629-X_11

[Czerniachowska & Marcin, 2021] Czerniachowska, Kateryna, and Marcin Hernes. "Simulated Annealing Hyper-Heuristic for a Shelf Space Allocation on Symmetrical Planograms Problem." Symmetry 13, no. 7 (2021): 1182.

[Dataset, 2022] Dataset for the distribution of pilgrims to the tents of Mina. Available at: https://uquadmin-my.sharepoint.com/:x:/g/personal/myshambour_uqu_edu_sa/EROZdUoLBHhAkQPg2k9u_q4BUaru_hJV-rVQZfPCAqLNuw?e=JeAg1A, last accessed April. 2022.

[Demirel et al., 2017] Demirel, Nihan Çetin, and Muhammet Deveci. "Novel search space updating heuristics-based genetic algorithm for optimizing medium-scale airline crew pairing problems." International Journal of Computational Intelligence Systems 10, no. 1 (2017): 1082-1101.

[Deveci et al., 2018] Deveci, Muhammet, and Nihan Çetin Demirel. "Evolutionary algorithms for solving the airline crew pairing problem." Computers & Industrial Engineering 115 (2018): 389-406.

[Drake et al., 2019] Drake, J. H., Kheiri, A., Özcan, E., & Burke, E. K. Recent advances in selection hyper-heuristics. European Journal of Operational Research, (2019), 285(2), 405-428. https://doi.org/10.1016/j.ejor.2019.07.073

[Edrees, 2013] Edrees, Mohammed, "An Urban Study of Crowdness in Muna and Jamarat Area", Journal of King Abdulaziz University: Environmental Design Sciences, 139.3180 (2013), 159-192. DOI: 10.4197/ Env. 7.4

[GAS, 2021] General Authority for Statistics, "https://stats.gov.sa", last access: Nov. 2021.

[Kabirzadeh et al., 2017] Kabirzadeh, S., Rahbari, D., & Nickray, M. A hyper heuristic algorithm for scheduling of fog networks. In 2017 21st Conference of Open Innovations Association (FRUCT), (2017), pp. 148-155. IEEE.

[Katoh N. & Ibaraki, 1998] Katoh N., Ibaraki T. Resource Allocation Problems. In: Du DZ., Pardalos P.M. (eds) Handbook of Combinatorial Optimization. Springer, Boston, MA. (1998), https://doi.org/10.1007/978-1-4613-0303-9_14

[Katoh et al., 2013] Katoh N., Shioura A., and Ibaraki T. Resource Allocation Problems. In: Pardalos P., Du DZ., Graham R. (eds). Handbook of Combinatorial Optimization. Springer, New York, NY. (2013)

[Kheiri et al., 2016] Kheiri, A., Özcan, E., & Parkes, A. J. A stochastic local search algorithm with adaptive acceptance for high-school timetabling. Annals of Operations Research, (2016), 239(1), 135-151.

[Kheiri & Keedwell, 2017] Kheiri, Ahmed., Keedwell, Ed. A hidden markov model approach to the problem of heuristics selection in hyper-heuristics with a case study in high school timetabling problems. Evol. (2017). Comput.25(3), 473–501

[Kheiri, et al., 2021] Kheiri, Ahmed, Angeliki Gretsista, Ed Keedwell, Guglielmo Lulli, Michael G. Epitropakis, and Edmund K. Burke. "A hyper-heuristic approach based upon a hidden Markov model for the multi-stage nurse rostering problem." Computers & Operations Research 130 (2021): 105221.

[Leng et al., 2019] Leng, L., Zhao, Y., Wang, Z., Zhang, J., Wang, W., & Zhang, C. A novel hyper-heuristic for the biobjective regional low-carbon location-routing problem with multiple constraints. Sustainability, (2019). 11(6), 1596.

[Olgun et al., 2021] Olgun, B., Koç, Ç., & Altıparmak, F. A hyper heuristic for the green vehicle routing problem with simultaneous pickup and delivery. Computers & Industrial Engineering, 153, 107010, (2021).

[Oteiza et al., (2021)] Oteiza, Paola P., Juan I. Ardenghi, and Nélida B. Brignole. "Parallel hyper-heuristics for process engineering optimization." Computers & Chemical Engineering 153 (2021): 107440.

[Ozcan et al., 2008] Ozcan, E., Bilgin, B., Korkmaz, E.E., A comprehensive analysis of hyper-heuristics. Intelligent Data Analysis (2008), 12, 3–23. DOI: 10.3233/IDA-2008-12102

[Pour et al., 2018] Pour, S. M., Drake, J. H., & Burke, E. K. A choice function hyper-heuristic framework for the allocation of maintenance tasks in Danish railways. Computers & Operations Research, (2018). 93, 15-26.

[Shambour, 2021] Shambour, Mohd Khaled, "Assessing the Usability of Hajj and Umrah Websites", International Conference on Information Technology (ICIT), pp. 876-881, (2021), doi: 10.1109/ICIT52682.2021.9491780.

[Shambour et al., 2013] Shambour, Mohd Khaled, Tajudin A. K., Kheiri A., and Özcan E., "A two stage approach for high school timetabling." In International Conference on Neural Information Processing, Springer, Berlin, Heidelberg, 2013, pp. 66-73.

[Shambour & Dhubaib, 2022] Shambour Mohd Khaled & Hani Dhubaib A., Analyzing The Feelings of Social Media Users During The Hajj Season 1442 AH. In: 21th Scientific Symposium for Hajj, Umrah & Madinah Visit, Madinah, Saudi Arabia, pp. 183-196 (2022).

[Shambour & Gutub, 2021] Shambour, Mohd Khaled, and Adnan Gutub. "Progress of IoT research technologies and applications serving Hajj and Umrah." Arabian Journal for Science and Engineering (2021): 1-21.

[Shambour & Khan, 2019] Shambour Mohd Khaled Y. & Khan Esam A., A Heuristic Approach for Distributing Pilgrims over Mina Tents, Journal of King Abdulaziz University: Engineering Sciences, 30 (2), (2019), 11-23. DOI:10.4197/Eng.30-2.2

[Shambour & Khan, 2022] Shambour Mohd Khaled & Khan Esam A., Using Artificial Intelligence Algorithms to Improve the Scheduling Mechanism of Pilgrims' Flights. In: 21th Scientific Symposium for Hajj, Umrah & Madinah Visit, Madinah , Saudi Arabia, pp. 208–217 (2022).

[Shambour et al., 2017] Shambour, Mohd.; Khan, E.; Salibi, A.: Distribute Mina camps automatically to increase the capacity and efficiency. In: 17th Scientific Symposium for Hajj, Umrah & Madinah Visit, pp. 720–726 (2017).

[Steenson et al., 2021] Steenson, Alexander and Özcan, Ender and Kheiri, Ahmed and McCollum, Barry and McMullan, Paul. An online learning selection hyper-heuristic for educational timetabling. In: Proceedings of the 13th International Conference on PATAT. UNSPECIFIED, BEL, pp. 129-146. (2022). ISBN 978-0-9929984-3-1

[Tan et al., 2019] Tan, B., Ma, H., & Mei, Y. A hybrid genetic programming hyper-heuristic approach for online two-level resource allocation in container-based clouds. In 2019 IEEE Congress on Evolutionary Computation (CEC) IEEE (2019). pp. 2681-2688.

[Vincent et al., 2020] Vincent, F. Yu, Renan Maglasang, and Yu-Chung Tsao. "A reduced variable neighborhood search-based hyperheuristic for the shelf space allocation problem." Computers & Industrial Engineering 143 (2020): 106420.

[Yilmaz & Başçiftçi, 2021] Yilmaz Acar, Z., Başçiftçi, F. Solving Multi-Objective Resource Allocation Problem Using Multi-Objective Binary Artificial Bee Colony Algorithm. Arab J Sci Eng 46, 8535–8547. 2021. https://doi.org/10.1007/s13369-021-05521-x

[Zhang W., 2002] Zhang, W. Modeling and solving a resource allocation problem with soft constraint techniques. Technical report: Wucs-2002-13, Washington University, Saint-Louis, Missouri, pp.1-19, 2002.

[Zhao et al., 2021] Zhao, Yanwei, Longlong Leng, and Chunmiao Zhang. "A novel framework of hyper-heuristic approach and its application in location-routing problem with simultaneous pickup and delivery." Operational Research, 21(2), 1299-1332, 2021.