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RESEARCH ARTICLE

Optimal Travel Planning of Short Stays in Mass Tourist Destinations

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ABSTRACT Tourism has become a dominant economic activity in coastal, historical, and mountainous locations. To address the negative impacts of mass tourist arrivals, this study presents an approach for promoting Sustainable Tourism Development in small, vulnerable destinations. Specifically, we focus on mitigating the adverse effects of short-stay tourism, which often leads to peak tourist densities and safety concerns. We propose a novel touristic trip design model, aiming to reduce peak tourist demand by optimizing scheduling in strategic destinations. This approach considers three critical aspects: maximizing tourist satisfaction, optimizing transport resource usage, and respecting maximum carrying capacities. Methodologically, we adopt a Network Flow Problem formulation solved using a Time Expanding Network. A Time Expanding Network provides a static representation of the network for each discrete time interval, ensuring travelers' satisfaction and the overall duration of their visit. We conducted a case study in Liguria Region, Italy, comparing our model's performance with an innovative heuristic approach. Results show the superiority of our approach in managing tourist flows and promoting sustainability. This research contributes valuable insights for achieving Sustainable Tourism Development in vulnerable touristic areas, assisting policymakers and stakeholders in making informed decisions for harmonizing tourism and environmental preservation.

INDEX TERMS Time expanded networks, tourist flow control, travel planning problem, tourism carrying capacity, sustainable tourism development, network flow problem, tourist trip design problem.

I. INTRODUCTION

In recent years, tourism has emerged as the dominant economic activity in coastal, historical, and mountainous locations. However, it is crucial to consider both the positive and negative impacts of tourism from economic, environmental, and social perspectives. Sustainable Tourism Development (*STD*) and the quality of life in touristic locations are closely interconnected, as indicated by the research literature [1]. In general, *STD* aims to minimize the negative impacts on cultural heritage and on the environment. Simultaneously, it should yield positive benefits for the local economy, leading to the enhancement of community services and infrastructures. The UNESCO World Heritage and Sustainable Tourism Programme has outlined strategies to address and manage potential threats and impacts on tourism [2]. *STD* cannot be achieved if touristic locations are impacted by mass tourism without implementing adequate integrated sustainability measures [3]. From this perspective, the *STD* analysis should primarily focus on the demand factor, especially when dealing with small touristic destinations [4]. Some research studies, like [5], propose an approach to analyze users' interests through social networks, thereby contributing to the sustainable growth and development of the tourism industry. In [6], the authors offer references to enhance destination revenue and achieve efficient visitor management. Additionally, [7] presents a study that explores the use of IoT-based techniques to improve tourism services. Recently, web-based or mobile-based tourist expert systems have been proposed to plan customized touristic tours based on users' interests and the attractiveness of locations [8], [9]. Several studies focus on demand-based touristic itinerary planning,

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taking into account visitors' preferences, travel distances, or costs [10]. Generally, the problem of defining the best tours for travelers based on their preferences falls under the classification of the Tourist Trip Design Problem. In [11], the authors explore various models, algorithmic approaches, and methodologies related to the *TTDP*, considering both single and multiple tour scenarios. Within the context of *TTDP*, the Orienteering Problem aims to maximize the total profit obtained from visiting specific nodes while ensuring that the paths adhere to the time allocated for sightseeing the nodes within a single day [12], [13]. In [14], the authors proposed a heuristic approach, which aims at defining the tour routes for heterogeneous tourist groups balancing the total utility of the group and the fairness of individual members. Besides, in [10], the authors solved the *TTDP* taking into account the individual preferences of the tourists about points of interests and the concept of mutual social relationship between the different tourists. They compared the solution of the *TTDP* for four cases: the generation of single tours where each tourist have one trip plan; the generation of tours for each subgroup of tourists built considering to aggregate the tourists with common preferences; a joint trip plan for all tourists considering the social relations of each pair of tourists; and, finally, a combined solution in which some parts of the itineraries may be shared by tourists with similar interests while other parts of the tour may be personalized based on the single individual preferences. In [15], the authors solved a *TTDP* implementing a time-dependent shortest path through a fixed sequence of nodes. Given the predefined large size of the time-dependent network, the authors proposed a decomposition approach to solve a sequence of smaller subproblems in reasonable computation times. Based on the *TTDP* problem concept, the authors in [16] train the Pointer Network model, by sampling variables that can change across tourists visiting a particular instance-region: starting position, starting time, available time, and the scores given to each point of interest. The study demonstrates that the proposed model generalizes well across different tourists visiting various regions. Moreover, the model consistently outperforms the most commonly used heuristic approach, providing superior solutions while maintaining realistic computation times. In [17], the authors developed a mathematical model - as well as related efficient algorithms - to solve a *TTDP* with the objective to design a tour trip to visit the most desirable tourists' sites subject to various budget and time constraints. In [18], the authors proposed an approach to generate dynamic routes for shared buses in the last mile scenarios considering travel requirement prediction and dynamic routes planning. In [19], a time-dependent *TTDP* has been solved in large urban areas for different groups of people. The authors define a chronological sequence of attractive points to be visited during a specific period via several modes of transportation. A large survey about models, algorithmic approaches, and methodologies concerning *TTDP* is presented in [11]. In addition, the similarities between this problem and parking problem issues are noteworthy. Designing parking guidance systems relies on a critical parking information release strategy. Additionally, parking choice models take into account waiting time and driver preferences [20], [21], [22].

In this paper, our objective is to introduce an approach to promote *STD* specifically tailored for close and small touristic locations. We address the *STD* aspects concerning short tourist stays, which often lead to peaks of tourist density that could potentially impact safety. Our approach makes a dual contribution. Firstly, we present a specialized structure of the *TTDP* model that optimally schedules touristic tours across a set of strategic and attractive destinations. Our objective is to reduce the peaks of touristic demand by considering three critical factors: maximizing tourists' satisfaction, optimizing the use of available transport resources, and respecting the maximum carrying capacity threshold in each location. Secondly, from a methodological standpoint, we model the problem as a Network Flow Problem (*NFP*) [23], which we solve using a Time Expanding Network (*TEN*) methodology [24]. The *TEN* approach provides a static representation of the original network for each discrete time interval and then solves the *NFP* for each interval [25]. This methodology has been effectively employed in various flow network problems, including evacuation problems [23], multi-depot bus scheduling [26], optimal capacity utilization for intelligent transportation management [27], air traffic delay reduction [28], and resource-constrained shortest-path problems [29].

The *TEN* approach provides a static representation of the network for each discrete time interval and solves the *NFP* for each interval [25]. It has been effectively applied in various flow network problems, including evacuation [23], multi-depot bus scheduling [26], intelligent transportation management [27], air traffic delay reduction [28], and resource-constrained shortest-path problems [29]. The proposed *TEN* based *TTDP* model optimizes travel plans for different tourist groups (*GT*s) visiting attractive locations. It considers *GT*s' desired locations, visit duration, and transportation modes. The model aims to maximize tourist satisfaction while minimizing deviations from planned durations, enhancing the tourism experience. The objective function uses a min-max approach to balance tourist distribution and manage visitor density at each location, ensuring a sustainable tourism experience. Existing literature traditionally *TTDP* models solutions from tourists' viewpoint, focusing on parameters related to tourist satisfaction, economic costs, visiting time, travel distance, transit duration, and transportation availability. Furthermore, the Smart City Tourism network introduces a mathematical model aimed at determining optimal tourist routes, utilizing a wealth of data about popular tourist destinations [30].

This paper tackles the requirement to effectively oversee and enhance *STD* within Italy's Cinque Terre National Park. The approach put forth here offers a safeguarding mechanism for sites of ecological and historical significance that have been impacted by a substantial influx of tourists.

The underlying mathematical model devises the best possible sequences for tourist itineraries, drawing on insights about various attractions. What sets this proposed method apart is its consideration of the standpoint of local authorities, who seek to preserve their regions by minimizing the influx of tourists during peak times while still maintaining planned visit schedules.

The rest of this paper is organized as follows. Section II introduces the *TEN* methodology. Section III describes the analysis of tourist carrying capacity. In Section IV, the model formulation of the *TEN* based on *TTDP* is presented. Section V showcases the heuristic algorithm used to evaluate the performance of the *TEN* approach. In Section VI, the case study is described, followed by the presentation of results from the proposed methods in Section VII. Finally, Section VIII discusses the conclusion and future developments

II. TIME EXPANDED NETWORK

A *TEN* is considered as a comprehensive paradigm utilized to depict intricate systems within the framework of dynamic network optimization problems. In the realm of literature, one of the primary conventional methodologies for network optimization across various application contexts like transportation, logistics, or communication involves the category of network flow models. In numerous real-world scenarios, where the transfer of flow from one node to another is not instantaneous, the classical static network flow approaches necessitate adjustments that incorporate the temporal dimension to model the progression of flows within the network over time. Ford and Fulkerson [31] introduced such models that account for the temporal variability in flow. In [19], a comprehensive overview of path and flow predicaments within generalized networks is presented. In essence, the *TEN* serves as a replica of the static flow network duplicated in each time interval of the overarching time horizon [32].

Let $Z = (N, A)$ be a network: where N is the set of nodes representing the locations, and A is the set of arcs representing the infrastructure connections (e.g. train, ship, …) between such locations (Fig. 1a). For a given time set $T = \{t_1, t_2, .., t_T\}$, the corresponding *TEN*, $Z^T = (N^T, A^T)$ (Fig. 1b) is defined as follows. For each node $c_i \in N$ of the network, a copy of that node has to be created for each time interval of the time horizon, labeled as c_{it} that is

$$N^T := \{c_{it_s} | t_s \in T, i = 1, .., N\} \tag{1}$$

For each arc $a_{ij} = (c_i, c_j) \in A$ of the network, if a mean of transport exist at that instant, there will be an instance of that arc $a_{ij}(t_s t_d)$, connecting nodes c_{it_s} to c_{jt_d}. In addition, the *TEN* also consists of holdover arc (c_{it_s}, c_{it_s+1}) for each $c_i \in N$ of the static network. These arcs allow holding the flows on the same nodes for more than one-time interval. The set of arcs is defined as follows

$$A^T := \{a_{ij}(t_s t_d) | a_{ij} = (c_i, c_j) \in A, t_s, t_d \in T, t_d > t_s\} \tag{2}$$

III. CARRYING CAPACITY OF A TOURIST DESTINATION

In order to adopt *STD* strategies balancing the requirements for the conservation and the attractiveness of touristic locations, a tourist carrying capacity (*TCC*) analysis has to be done. Here, a *TCC* is mainly referred to the definition proposed by World Trade Organization as "The maximum number of people that may visit a tourist destination at the same time, without causing destruction of the physical, economic, socio-cultural environment and an unacceptable decrease in the quality of visitors' satisfaction" [33], [34]. More recently, this definition has been integrated taking into account the impact of touristic flows which has not to affect negatively the quality of life of community residents [35]. For a brief review about the *TCC*, the reader can refer to [36].

The goal is to present a suitable methodology to compute the maximum threshold value for the *TCC* for small sensible locations on the coastal areas. In literature, the methodologies to compute *TCC* are based on physical, biological, and management conditions of the selected locations [37]. Such three characteristics are defined as three connected indices: the physical carrying capacity (*PCC*), the real carrying capacity (RCC), the effective carrying capacity (*ECC*) [36]. The following indices can be computed as in [36]:

$$PCC = \frac{Area}{A_u} R_f \tag{3}$$

where

- *Area* is the size of the physical area visited by tourists
- A_u represents the minimum space required by each tourist
- R_f is the rotation factor which means the number of times the selected location can be visited per day

The *RCC* is determined by reducing the *PCC* through correction factors associated to environmental features (sunshine, rainfall, soil erosion, biological disturbance).

$$RCC = PCC \prod_{i=1}^{k} cf_i \tag{4}$$

The generic correction factor is normailized using equation (5)

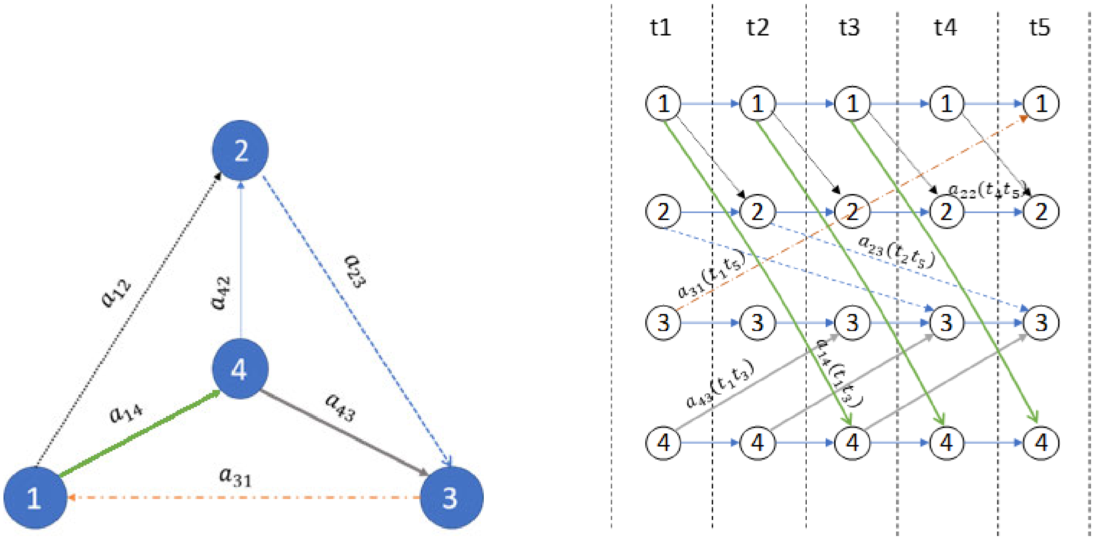
$$cf_i = 1 - \frac{Lm_i}{Tm_i} \tag{5}$$

where Lm_i is the limiting magnitude of $i-$th environmental factor, and Tm_i is its total magnitude. Finally, *ECC* is equal to *RCC* times the parameter *mc* which is associated with the quality of the management and infrastructures given by the visited location ($mc \leq 1$).

$$ECC = RCC * mc \tag{6}$$

IV. *TEN* BASED *TTDP* MODEL FORMULATION

In this section, the proposed *TEN* based *TTDP* model is presented to find the optimal planning and the temporal sequences of attractive locations to be visited by a set *GT*s during a specific period by using several modes of transport



(a) (b)

FIGURE 1. A network G with 4 nodes and 6 arcs. The different line dashes and colors are related to different transport modalities (1b.) The representation of the same network with the same colors according to the TEN *GT* with time horizon T = 5.

services. In the static network, the set N of touristic locations, are connected by the set A of arcs which represent the transport services from location i-th to location j-th with a specific time transit. Due to the dynamic nature of the proposed problem, a *TEN* expanding the static network over the planning horizon for every time interval has been defined. The time intervals are not considered constant but they are defined according to the travel time for the related transport service between nodes. Each time interval is converted to the timetable of transport services according to the departure and arrival time from origin to destination location. In this way, the number of the time interval to build the *TEN* is reduced only to the number of actual transport services available in the selected time horizon.

A. VARIABLES AND PARAMETERS OF THE TEN BASED TTDP MODEL

The following variables and parameters are introduced.

- $G = \{1 \ldots . g\}$ is the *GT* set. Each GT has to be considered as an indivisible group of persons.
- $N^T := \{c_{it_s} | t_s \in T, i = 1, .., N\}$ is the set of nodes. Each node represents a specific location in the network and it has a related ECC_i in term of allowed visiting tourists. Two fictitious nodes have also been added: the super source and the super sink, which indicate the virtual starting node of all the visits, before entering the first city to be visited; and the super sink, destination after leaving the last visited node. In the case of fictitious nodes, the ECC_i is unlimited
- $A^T = (c_{it_s}, c_{it_d})$ is the set of arcs of the *TEN* network;
- Set of time intervals which the time horizon consists of, $T = \{t_1, t_2, .., t_T\}$. The proposed network system has an event-driven dynamics. Each discrete time point $t_1 < t_2 < .. < t_k < .. < t_T$ represents the occurrence of an event associated to the arrival or departure times of a transport service.
- Set of modes of transport, $M = \{1 \ldots m\}$ available modes of transport are represented by the arcs between nodes of the network. Each mode of transport has a related maximum capacity in number of allowed people to be transported (CAP_m).

The following parameters have been introduced:

- w_g number of persons which the $g-$th GT, $g \in G$, consists of,
- $Start_g$ planned starting time of the tour of each $g-$th GT, $g \in G$,
- d_{m,c_i,t_i,c_j,t_j} Binary parameter equal to 1 if a transit is available by the $m-$th mode of transport between the nodes c_i and c_j, from the time instant t_i, to t_j with t_i, $t_j \in T$, c_i, $c_j \in N$, $m \in M$
- ECC_c Maximum ECC allowed in term of visiting tourists at the node c_i, $c_i \in N$
- CAP_m Capacity (in number of allowed transported persons) of $m-$th mode of transport, $m \in M$
- $\hat{t}_{g,c}$ Planned visiting duration of $g-$th group at the $c-$th node, $g \in G$, $c \in N$
- O_t Real time for the event (arrival or departure times of the transport service) associated to the related time instant $t_i \in T$

The following decision variables have been introduced:

- y_{m,g,c_i,c_j,t_i,t_j} Binary variable equal to 1 if the $g-$th GT uses a transport service by the $m-$th mode of transport at time instant ti at the node c_i to reach the node c_j at time instant t_j, c_i, $c_j \in N$, $m \in M$, t_i, $t_j \in T$, $g \in G$
- yp_{m,c_i,c_j,t_i,t_j} Total number of tourists allocated to a transport service carried out by the $m-$th mode of transport

at time instant ti at the node c_i to reach the node c_j, with $c_i, c_j \in N, m \in M, t_i, t_i \in T, g \in G$

- $x_{c,t}$ Number of visiting tourists at the node ci at time instant t_i, $c_i \in N$, $t_i \in T$
- $STOCK_{c,t}$ Percentage of occupied effective carrying capacity ECC_{c_i}, at the node c_i at time instant t_i, $c_i \in N$, $t_i \in T$
- $t_{g,c}$ Optimal visiting duration of $g-$th GT at the $c-$th node, $g \in G, c \in N$
- t_g^{end} Optimal end time of the tour for each $g-$th GT, $g \in G$

B. OPTIMAL TEN BASED TTDP MODEL

The multi-objective function of the model addresses various aspects of the *TTDP* problem. It aims to optimize tourist satisfaction, reduce the maximum site occupancy to prevent overcrowding, and minimize the visit duration for each group.

1) OBJECTIVE FUNCTIONS

$$
\begin{aligned}
OB_1 &= \min \sum_{c,t} STOCK_{c_i,t_i}(O_{t+1} - O_t) \\
OB_2 &= \min \sum_{g,c} w_g(\hat{t}_{g,c} - t_{g,c})^2 \\
OB_3 &= \sum_{g} t_g^{end} \\
&\min \alpha OB_1 + \beta OB_2 + \gamma OB_3 \qquad (7)
\end{aligned}
$$

where α, β, and γ are weight parameters that implement the preference factors that identify the relative importance of objectives.

The OB_1 objective implements a minmax approach by minimizing the maximum value of tourists allocated to each visited location during the overall time horizon in order to prevent massive touristic arrivals. The second objective OB_2 aims at minimizing the square deviation of the time spent by the GT_s to compute their visiting tours in respect to the planned ones. The third objective minimizes the ending time of the tour for each GT in order to guarantee that the tourists cover the path at minimum cost in the network in term of travel duration.

2) CONSTRAINTS

$$
\begin{aligned}
&x_{c_i,t_i} = \sum_{g} y_{1,g,\, c_i,c_i,t_i,t_{i+1}} w_g \quad c_i = 2,..,N-1 \\
&t_i = 1,..,T-1 \qquad (8)
\end{aligned}
$$

$$
\begin{aligned}
&\frac{x_{c_i,t_i}}{ECC_{c_i}} \le STOCK_{c_i,t_i} \quad c_i = 2,..,N-1 \\
&\quad t_i = 1,..,T-1 \qquad (9)
\end{aligned}
$$

$$
\begin{aligned}
&yp_{m,\, c_i c_j,t_i,t_j} = \sum_{g} y_{m,g,\, c_i,c_j,t_i,t_j} w_g \quad m = 1,..,M \\
&\quad c_i, c_j = 2,..,N-1 \\
&\quad t_i, t_j = 1,..,T-1 \qquad (10)
\end{aligned}
$$

$$
\begin{aligned}
&yp_{m,\, c_i c_j,t_i,t_j} \le CAP_m \quad m = 1,..,M \\
&\quad c_i, c_j = 2,..,N-1 \\
&\quad t_i, t_j = 1,..,T-1 \qquad (11)
\end{aligned}
$$

$$
\begin{aligned}
&y_{m,g,\, c_i,c_j,t_i,t_j} \le d_{m,c_i,t_i,c_j,t_j} \quad g = 1,..,G \\
&\quad m = 1,..,M \\
&\quad c_i, c_j = 2,..,N-1 \\
&\quad t_i, t_j = 1,..,T-1 \qquad (12)
\end{aligned}
$$

$$
\begin{aligned}
&t_{g,\, c_i} = \sum_{m,c_i,t_i,t_j} \left[O_{t_j} - O_{t_i}\right] y_{m,g,\, c_i,c_i,t_i,t_j} \quad g = 1,..,G \qquad (13) \\
&\quad c_i = 2,..,N-1
\end{aligned}
$$

$$
\begin{aligned}
&\sum_{m,\, c_i \neq c_j,t_i,t_j} y_{m,g,\, c_i,c_j,t_i,t_j} \le 1 \quad g = 1,..,G \\
&\quad c_j = 2,..,N-1 \qquad (14)
\end{aligned}
$$

$$
\begin{aligned}
&\sum_{m,c_i,t_i<t_j} y_{m,g,c_i,c_j,t_i,t_j} = \sum_{m,c_h,t_h>t_j} y_{m,g,c_j,c_h,t_j,t_h} \\
&\quad g = 1,..,G \\
&\quad c_j = 2,..,N-1 \\
&\quad t_j = 1,..,T \qquad (15)
\end{aligned}
$$

$$
\sum_{m,c_j,t_i,t_j} y_{m,g,\, 1,c_j,t_i,t_j} = 1 \quad g = 1,..,G \qquad (16)
$$

$$
\sum_{m,c_i,t_i,t_j} y_{m,g,\, c_i,N,t_i,t_j} = 1 \quad g = 1,..,G \qquad (17)
$$

$$
\begin{aligned}
&\sum_{m,c_i,c_j,t_i,t_j} y_{m,g,\, c_i,c_j,t_i,t_j} = 0 \quad g = 1,..,G \\
&\quad t_i < Start_g \qquad (18)
\end{aligned}
$$

$$
\begin{aligned}
&\sum_{m} y_{m,g,\, c_i,c_j,t_i,t_j} . O_{t_j} < t_g^{end} \quad g = 1,..,G \\
&\quad c_i, c_j = 2,..,N-1 \\
&t_i, t_j = 1,..,T-1 \qquad (19)
\end{aligned}
$$

By equations (8), the number of tourists belonging to the *GTs*, which visit each node in each time interval, is computed. The *NET* is built considering that the stays in each location are implemented by the holding arcs which allow to transits, on the same node, for more than one time interval. In the proposed model, the transport services given by the first transport mode ($m = 1$), by walking, is realized by the transiting on the holding arcs. Constraints (9) implement the min max decision making which implies to minimize the possible worst scenario in which the ECC_{c_i} is total occupied in each node c_i. The occupancy threshold, which varies between 0 and 1, is identified by the variable $STOCK_{c_i,t_i}$ which is limited by the ratio between the actual number of tourists present in the location in each time interval and the maximum available capacity ECC_{c_i}. By eq. (9) and by minimizing the variable $STOCK_{c_i,t_i}$ in OB_1, it is guaranteed the minimization of the maximum value of occupancy of ECC_{c_i}.

Constraint (10) computes, for each transport service, the number of tourists allocated to the transport resources. Constraint (11) verifies that the threshold of the maximum capacity of each transport resource is respected.

Constraint (12) guarantees that the *GTs* only access to existing arcs and so to available transport services. Constraint (13) defines, for each *GT*, the visit time of each node.

By equation (14), the model constrains the *GT* to visit each node only once. Constraint (15) realizes the flow conservation at each node of the *TEN* in each time interval. Constraints (16) and (17) manage the touristic flow in the specific case of source and sink nodes. In constraint (18), the model guarantees that each *GT* cannot start its tour before its planned arrival time in the source node. Constraint (19) deals with minimizing the total travel time spent by each *GT* in the network.

3) PROBLEM COMPLEXITY

The problem is quadratic in the cost function, with linear constraints. However, the large amount of binary variables makes the problem complexity *NP*-hard, as solved by classic mathematical programming techniques. On the other hand, it is worthwhile to observe that in typical instances of the problem, just few *TEN* nodes are linked together). In addition, the application is at the planning level, with no strict requirements on its computation. So, the optimal solution can be found in a reasonable and feasible time for small problems as the one proposed here in the case study.

V. HEURISTIC APPROACH

In order to evaluate the model on larger instances, a heuristic approach to solve a *TTDP* has been introduced. The heuristic algorithm based on a longer visit first. It aims at defining, for each group of tourists, the best path to visit the planned touristic locations respecting the planned visiting time and favouring the tour on the nodes at minimum *ECC*.

The algorithm processes each group serially. Let *LG* the list of the *GTs* according to decreasing $\widehat{TD}_g$. The first *g* in *LG*, the group which has the maximum value of total duration of the planned visits, is the first which accesses on the *TEN Z*. The motivation that is at the basis of this heuristic is that longer stays are more difficult to be assigned to satisfy the objective. In this respect, the algorithm can be brought back to the well known first-fit decreasing algorithm used in bin packing problems [38]. The first group *g* consecutively visits the locations c_i according to the decrescent value of $\hat{t}_{g,c_i}$. The following groups, extracting consecutively from *LG* explore the *TEN Z* visiting the location which has the lower value of $STOCK_{c,t}$.

A. HEURISTIC ALGORITHM TEST

The proposed heuristic approach is illustrated through a test example involving three *GT*s and three locations served by two transport modes. The relevant data for each *GT*, including the number of tourists in each *GT* and the starting time of the tours, the planned duration of visits at each location, and the *ECC* for each site, are provided in Table 1, Table 2, and Table 3, respectively. Hereinafter, *LG* identifies the *GT* list quoted in Table 2, ordered by descending $\widehat{TD}_g$.

TABLE 1. ***GT*** **Data for the heuristic test: Number of tourists in each** ***GT*** **and the starting time of the tours.**

GT	w_g	$Start_g$
*GT*1	15	1
*GT*2	10	1
*GT*3	11	2

TABLE 2. ***GT*** **data for the heuristic test: Planned duration of visits at each location.**

$\hat{t}_{g,c}$	c_1	c_2	c_3	$\widehat{TD}_g[min]$
*GT*1	12	15	6	33
*GT*2	12	11	14	37
*GT*3	10	16	6	32

TABLE 3. ***GT*** **data for the heuristic test:** ***ECC*** **for each site.**

	c_1	c_2	c_3
ECC	35	30	40

For the heuristic approach, the following notations are introduced:

- let $ht^{t_i}_{g,c}$ the visiting duration at the node c, at the time instant t_i for the $g-th$ *GT*;
- let $ht_{g,c}$ the total visiting duration at the node c for the $g-th$ *GT* generated by the heuristic approach.

For the first group in *LG*, i.e., *GT*2, the sequence of nodes to be visited is c_3, c_1, c_2. It starts its tour in the network at time t_1 at the node c_3. The group *GT*2 remains at the current node until t_3 with a visiting time $t_{2,c_3} = 14$. At time t_3, *GT*2 leaves node c_3 and moves to the next node, covering the available arc in the network. Verifying that the persons of the group do not exceed the capability of the available means of transport, at time t_5, *GT*2 reaches node c_1. It stays at node c_1 until time t_7 with a visiting time $t_{2,1} = 12$. Unfortunately, at the current node, no transport service is available to reach other nodes.

*GT*2 may move horizontally in the network, in the next or in the previous time instants for the current node, respectively at node $c_{1_{t_6}}$ or $c_{1_{t_8}}$. In order to evaluate the best solution, the divergence between the visiting times in the two options is compared with the planned one (see Procedure 1). To minimize the divergence with respect to the planned visiting time, *GT*2 comes back to node $c_{1_{t_6}}$. At this node, *GT*2 is able to move toward node c_2, which is visited until time t_{10}.

The next group in *LG* is *GT*1, which may start its tour at the first time interval. The nodes that may be reached by the origin of the network are c_1 or c_3. At the current time instant, the value $STOCK_{c_1,t_1} < STOCK_{c_3,t_1}$, so *GT*1 starts its tour at node c_1, covering the path that has the lower impact on the location occupancy. *GT*1 stays at the current node until t_3, and then it moves to the next node. Only the node c_2 is connected by an arc with capability to allow transit. Node $c_{2_{t_4}}$ becomes the next node to be visited. *GT*1 stays at node c_2 until t_6, reaching its desired visiting time $\hat{t}_{1,2} = 15$. Unfortunately, at node c_2, for the current time interval, no transport service is available. Again, in this case, the divergence between the visiting time and the planned one is compared for the previous

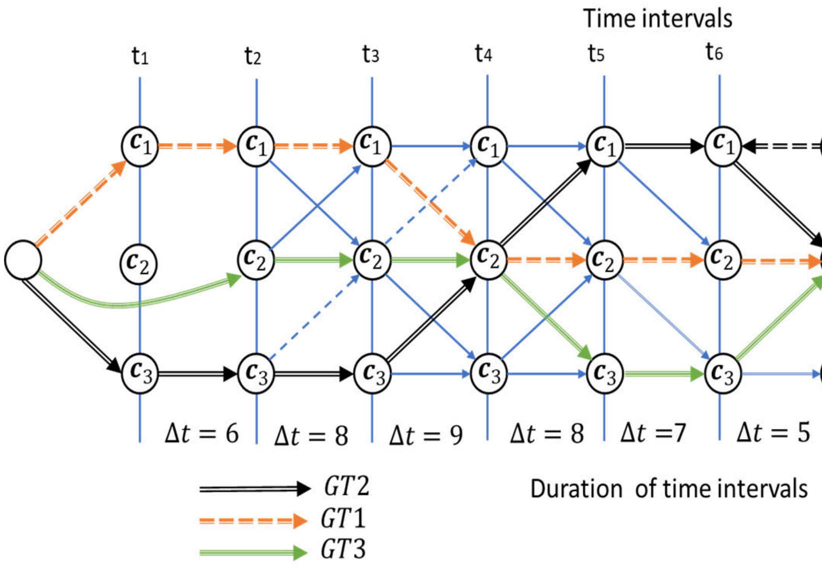


FIGURE 2. Proposed paths resulting from the heuristic approach.

TABLE 4. Occupancy of the locations in the heuristic test.

$STOCK_{c,t}$	c_1	c_2	c_3
t_1	42,90%	0,00%	25,00%
t_2	42,90%	36,70%	25,00%
t_3	42,90%	36,70%	25,00%
t_4	0,00%	86,70%	0,00%
t_5	28,60%	50,00%	27,50%
t_6	28,60%	50,00%	27,50%
t_7	0,00%	83,30%	0,00%
t_8	31,40%	33,30%	37,50%
t_9	31,40%	33,30%	37,50%
t_{10}	31,40%	33,30%	37,50%
t_{11}	31,40%	0,00%	0,00%

TABLE 5. Total duration of the tours generated by the heuristic test.

$ht^h_{g,c}$	c_1	c_2	c_3	Total duration	$\frac{\sum_c ht_{g,c}}{\sum_c \hat{t}_{g,c}}$
$GT1$	7	15	14	36	97%
$GT2$	14	20	7	41	124%
$GT3$	13	17	7	37	116%

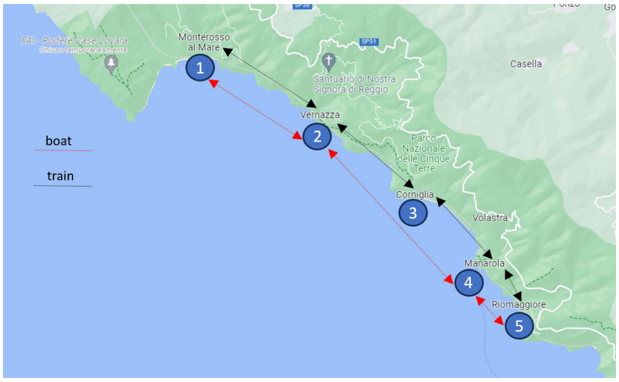


FIGURE 3. Cinque Terre case study, showing connections by ferry boat (on the sea) and by train (on the land).

and next time instants. In this case, $GT1$ stays at the current node until t_7, then it moves to the last node to be visited, c_3. Finally, $GT3$ has been processed. Its tour may start at time t_2 when only $STOCK_{c_2,t_2}$ is equal to zero. Thus, $GT3$ reaches firstly node c_2 by means of transport $m2$ and visits the node for 17 units of time. At instant t_4, the transport services are available to reach both nodes c_1 and c_3, and it results $STOCK_{c_3,t_5} < STOCK_{c_1,t_5}$. Node c_3 has been visited by $GT3$ for 7 units of time. Finally, the current group reaches and visits node c_1 transiting through node c_2. Figure 2 displays the paths followed by the three GTs. Table 4 presents the percentage of occupancy for each location, calculated as the ratio between the number of tourists and the corresponding ECC. Additionally, Table 5 shows the total duration of the generated tours. The last column on the right-hand side indicates the ratio between the total duration of the tours and the planned total duration, as presented in Table 2.

VI. CASE STUDY

The proposed models have undergone testing through a real case study, which focused on managing the substantial influx of tourists in the Cinque Terre National Park, situated in the Liguria region of Italy. The Cinque Terre National Park comprises five enchanting locations: Monterosso, Vernazza, Corniglia, Manarola, and Riomaggiore. These picturesque locations are connected by convenient transport services, including trains and ferry boats, which systematically take visitors on trips, commencing from the outermost points of the area, namely Monterosso or Riomaggiore. Cinque Terre, a UNESCO World Heritage site since 1997, is both a National Park and a Protected Marine Area, aimed at preserving its cultural and natural treasures. However, tourism has surged unsustainably, especially in summers. In 2018, it was projected that over 2 million tourists would visit Cinque Terre. For instance, Riomaggiore hosted 92 tourists per resident in 2018 [39].

TABLE 6. ***ECC* computation.**

Location	Area [m]	Area/Au	PCC per day	RCC per day	ECC per day
Monterosso	5451	1090	2907	2907	2035
Vernazza	5118	1023	2729	2730	1911
Corniglia	5154	1031	2749	2749	1924
Manarola	4456	891	2376	2376	1663
Riomaggiore	4636	927	2472	2472	1731

Recently, Cinque Terre has become a hotspot for tour operators, arranging rapid trips for large cruise ship groups from La Spezia or Genoa. Nearby regions also contribute to the surge. Daily, crowds arrive via trains or the local port, overwhelming these small villages with a few hundred residents. The excessive influx has led Cinque Terre's five municipalities to implement strategies to manage visitors and protect fragile environments.

The initial step in implementing *STD* involves identifying optimal strategies to manage the massive arrival of tourists. The proposed *TTDP* model, based on the *TEN*, endeavors to determine the most efficient tour for tourists planning a short stay to visit Cinque Terre in a day, respecting the *ECC* of locations and maximizing tourist satisfaction during their visits. According to the region's topography, the network comprises five nodes corresponding to the five attractive locations: Monterosso, Vernazza, Corniglia, Manarola, and Riomaggiore.

A. ECC DEFINITION FOR THE LOCATIONS IN CINQUE TERRE

To apply the proposed methodology and compute *ECC*, a Geographic Information Systems analysis has been carried out to quantify the areas of the main point of interest in the selected municipalities. The areas used to test the proposed methodologies only consist of the sites which are considered at risk and which suffer from significant overcrowding. From vector maps provided by Regione Liguria [40], the touristic areas of each municipality have been computed.

The value of the A_u is set to 5 m^2 for tourist [36]. The values of R_f correspond to the daily number of visits, considering that the touristic arrivals are usually planned by travel agencies in a range from 09:00 am to 05:00 pm. The average time of duration for visit has been assessed in 3 hours, thus the parameter is $R_f = \frac{8}{3} = 2.66$. The correction factors in the proposed case study have been set to 1, assuming that external and meteorological conditions do not significantly affect the *PCC* values. On the contrary, due to the problematic management of the territories and the negative aspects related to the complex geographical conformation of the area and its accesses, *mc* is considered equal to 0.7. Table 6 summarizes the data associated with the parameters used to compute *ECC* by equation (6).

B. CASE STUDY INPUT DATA

The case study considers managing the TTDP for 8 different *GTs* in a time horizon of 6 hours starting from 9 am. The *GTs* can reach the locations of Cinque Terre by two kinds of transport services, by train or by boat (as shown in Fig. 3). Data collection involves the use of sensors installed at train stations and key tourist facilities to monitor daily crowd levels. Train and boat schedules are accessible through the transport-related website.

The trains stop in each of the five locations which are visited consecutively. In the same way, boat services are available, but they don't stop at the location of Corniglia. A boat service from Monterosso to Riomaggiore is about 45 minutes long. The train services last about 18-20 minutes to visit the five locations. The timetables for the transport services are available on the Cinque Terre website. The *TEN* is extended for 130 time intervals and it contains more than 1500 arcs. The capacity associated to the transport resources, train and boat, has been set to 1000 and 350 travelers respectively. The number of tourists of each group w_g and the starting time $Start_g$ of visiting the first municipality are a priori known for each *GT*, see Table 7. The planned duration of the visits $\widehat{TD}_g = \sum_c \hat{t}_{g,c}\ \forall g \in G$ for each *GT* in each node are shown in Table 8.

TABLE 7. **Number of tourists in each *GT*.**

GT	w_g	$Start_g$
GT1	40	10:00
GT2	30	09:00
GT3	80	09:00
GT4	40	10:00
GT5	100	11:00
GT6	60	11:00
GT7	35	10:00
GT8	52	09:00

TABLE 8. **Planned duration of the visit for each *GT*.**

$t_{g,c}$	Monterosso	Vernazza	Corniglia	Manarola	Riomaggiore	$\widehat{TD}_g$
GT1	55	40	40	50	0	185
GT2	40	40	45	45	60	230
GT3	55	45	50	55	55	260
GT4	55	40	50	0	0	145
GT5	55	30	0	45	0	130
GT6	0	50	0	45	50	145
GT7	0	0	0	60	55	115
GT8	30	45	35	45	45	200

VII. RESULTS

This section reports the results obtained applying the model and the heuristic approach on the proposed case study. The proposed optimal *TEN* based *TTDP* model has been implemented by CPLEX software, while the heuristic one has been implemented in Matlab code.

The results provide the optimal *TTDP* for the selected *GTs* to reach their destinations. Table 9 shows the planned duration of the visit for each *GT*, as obtained by the *TEN* based *TTDP* model, which demonstrates the minimum squared divergence from the values in Table 8. Table 10 shows the related arrival and departure time for the optimal tour of each *GT* at each

TABLE 9. Optimal duration of the visits for each *GT* or the *TEN* based *TTDP* model.

$t_{g,c}$	Monterosso	Vernazza	Corniglia	Manarola	Riomaggiore	TD_g	$\frac{\sum_c ht_{g,c}}{\sum_c \hat{t}_{g,c}}$
$GT1$	55	48	37	50	0	190	103%
$GT2$	47	55	42	51	60	255	111%
$GT3$	48	55	42	51	60	256	98%
$GT4$	55	48	49	0	0	152	105%
$GT5$	58	30	0	43	0	131	101%
$GT6$	0	48	0	39	50	137	94%
$GT7$	0	0	0	58	53	111	97%
$GT8$	28	49	30	30	49	186	93%

TABLE 10. Arriving and departure time of each *GT* for the *TEN* based *TTDP* model.

Arriving and departure time	Monterosso	Vernazza	Corniglia	Manarola	Riomaggiore
$GT1$	10:10 - 11:05	11:09 - 11:57	12:01 - 12:38	12:42 - 13:32	
$GT2$	09:23 - 10:10	10:14 - 11:09	11:19 - 12:01	12:03 - 12:54	12:57 - 13:57
$GT3$	09:22 - 10:10	10:14 - 11:09	11:19 - 12:01	12:03 - 12:54	12:57 - 13:57
$GT4$	10:10 - 11:05	11:09 - 11:57	12:01 - 12:50		
$GT5$	12:41 - 13:39	12:06 - 12:36		11:06 - 11:49	
$GT6$		11:09 - 11:57		12:03 - 12:42	12:45 - 13:35
$GT7$				12:29 - 13:27	11:33 - 12:26
$GT8$	13:20 - 13:48	12:14 - 13:03	11:39 - 12:09	11:06 - 11:36	10:14 - 11:03

TABLE 11. Duration of the visits for each *GT* by the heuristic approach.

$ht_{g,c}$	Monterosso	Vernazza	Corniglia	Manarola	Riomaggiore	TD_g	$100\frac{\sum_c ht_{g,c}}{\sum_c \hat{t}_{g,c}}$
$GT1$	55	41	40	50	0	186	101%
$GT2$	47	49	46	45	60	247	107%
$GT3$	103	48	79	60	57	347	133%
$GT4$	55	41	40	0	0	136	94%
$GT5$	51	48	0	45	0	144	111%
$GT6$	0	50	0	48	51	149	103%
$GT7$	0	0	0	61	55	116	101%
$GT8$	47	49	38	45	45	224	112%

TABLE 12. Arriving and departure time of each *GT* by the heuristic approach.

Arriving and departure time	Monterosso	Vernazza	Corniglia	Manarola	Riomaggiore
$GT1$	11:19 - 12:14	12:28 - 13:09	13:20 - 14:00	14:24 - 15:14	
$GT2$	09:23 - 10:10	10:14 - 11:03	11:19 - 12:05	12:24 - 13:09	13:27 - 14:27
$GT3$	09:22 - 11:05	11:09 - 11:57	12:01 - 13:20	13:24 - 14:24	14:27 - 15:24
$GT4$	11:19 - 12:14	12:28 - 13:09	13:20 - 14:12		
$GT5$	11:06 - 11:57	12:06 - 12:54		13:50 - 14:35	
$GT6$		14:54 - 15:44		12:06 - 12:54	11:06 - 11:57
$GT7$				12:29 - 13:30	11:19 - 12:14
$GT8$	09:23 - 10:10	10:14 - 11:03	11:19 - 11:57	12:03 - 12:48	12:57 - 13:42

municipality. Tables 11 and Table 12 show the correspondent results obtained by the heuristic model.

It is evident that the models adhere to the planned locations in terms of the visited destinations, as the *GTs* visit the expected locations according to the scheduled starting time.

Upon analyzing the results obtained by the *TEN* based *TTDP* model, a comparison between the desired and the optimal duration of the visits reveals the following.

For $GT3$, $GT6$, $GT7$, and $GT8$, their total stay in the nodes is slightly less than the planned durations, with the maximum divergence between durations being only 7

For $GT1$, $GT2$, $GT4$, and $GT5$, they spend more time than initially planned. However, the maximum divergence in time is assessed at 11%, representing 25 minutes for $GT2$.

Regarding the transport modes, due to more frequent services, trains are the most commonly used resource by the *GTs*.

The performance of the heuristic approach is slightly lower than the optimal one. For example, the heuristic approach has lower performance on the most numerous *GT* (i.e., $GT5$, 100 tourists, with a deviation of 111% compared to the optimal one of 101%). In addition, taking into account the percentage deviations shown in Tables 8 and 12, the average divergence per tourist, taking into account the tourists for each group as described in 7 is respectively 99.5% and 110.5% for the optimal TEN approach and for the heuristic one.

In Figures 4 - 8, the black line shows the percentages of *ECC* occupation for each municipality during the time horizon for the optimal tours generating by the *TEN* based *TTDP* model.

In the optimal solutions, the most visited location, in the same time interval, is Manarola, with 12% of occupancy. This is due to the geographical conformation of the case study area which forces to visit the destination consecutively. The grey line defines the occupancy of *EEC* for each location according to the actual planned tours. The tours start according to the GTs' time arrivals and their related duration. The planned scheduling of tours starts at 9:00 a.m and stops 3 hours and 40 minutes later at maximum.

The dotted grey line represents the worst case. It is assumed that the GTs start their tour contemporaneously, and the

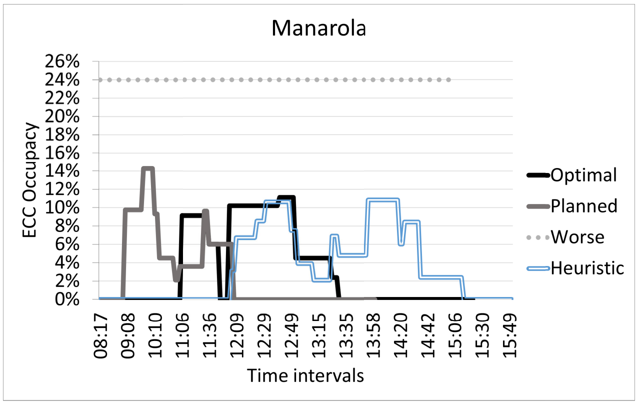


FIGURE 4. Occupancy of *ECC* in Manarola.

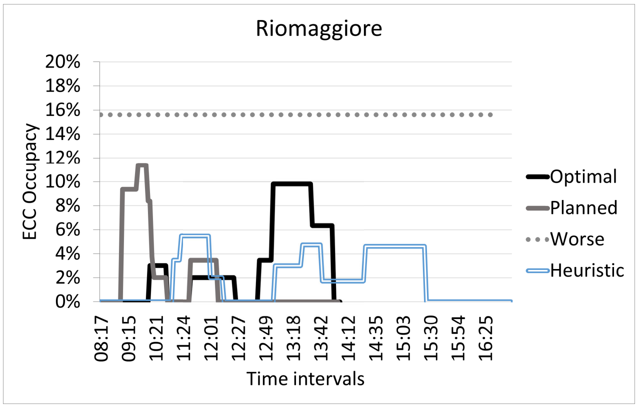


FIGURE 5. Occupancy of *ECC* in Riomaggiore.

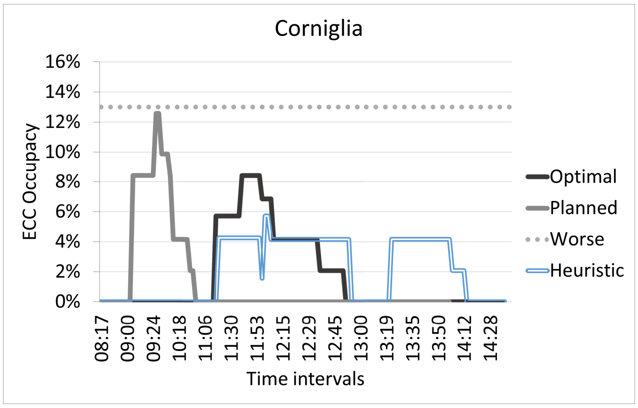


FIGURE 6. Occupancy of *ECC* in Corniglia.

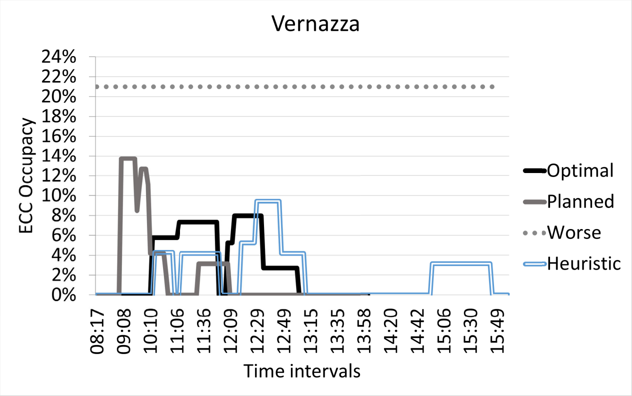


FIGURE 7. Occupancy of *ECC* in Vernazza.

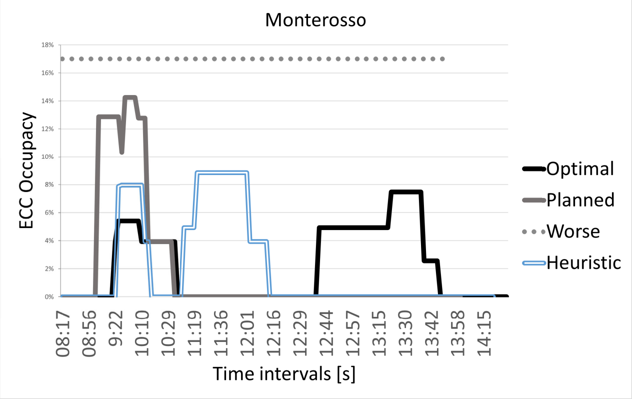


FIGURE 8. Occupancy of *ECC* in Monterosso.

straight line represents the maximum percentage of occupancy in each location considering the contemporary presence of the 8 *GT*s in each location. The optimal percentage of occupancy obtained by applying the model is always less than the values found for the planned ones. The double blue lines represent the solutions generated by the heuristic approach application. It is evident that the heuristic approach also aims at minimizing the impact of the massive touristic arrival. However, when the peaks of occupancy are lower in respect to the optimal solutions, the total visiting times of the eight groups have a significant increase. In the case of Riomaggiore municipality, the *ECC* occupancy in the heuristic solution is 2% lower than the optimal solution, but the total duration of the visits gets worse by 12%. The heuristic algorithm provides paths that exceed the planned total visiting time.

The main important issue to be highlighted related to the optimal *TEN* based *TTDP* model is represented by the shifting of the tours for the *GT*s, which have been postponed in respect to their planned arrival times without affecting the total duration of the visits in the selected locations. In the proposed optimal scheduling, the tours are planned in an extended time horizon in respect to the actual case. The GT8, which has to visit all five locations, as well as *GT*2 and *GT*3, starts its tour leaving from the last node Riomaggiore, carrying out the tour from node 5 to 1. In this way, the small delay is due to the longer transit to reach the first visited location. However, this shifting deals with the minimization of the maximum occupancy of *ECC* in the destinations on the overall time horizon. Also, the heuristic approach proposes to start the visits of *GT*6 and *GT*7 starting at node 5 toward node 1 to affect the same municipalities at the same time intervals.

As mentioned in subsection 4.3, it is essential to highlight the contrasting complexities between the *TEN* approach and the heuristic approach. While the *TEN* approach offers a more intricate and time-consuming solution process, the heuristic approach is significantly faster and simpler. However, it is essential to consider that the case study's instance is relatively small, similar to the problems encountered in small touristic locations.

VIII. CONCLUSION AND FUTURE DEVELOPMENT

This paper introduces a mixed integer optimization model for a *TEN*-based *TTDP*, tailored for brief visits to high-traffic tourist spots. The performance of the proposed optimal model is juxtaposed with an innovative heuristic technique. The case study focuses on a treasured and delicate tourist destination within the Liguria Region of Italy.

The principal aim of this study is to present a methodology that can aid local administrators in curbing the adverse effects of mass tourism in their regions. Rather than outright restricting access, the approach strives to regulate tourist arrivals while prioritizing residents' well-being and ensuring a positive visitor experience. Special emphasis is placed on preventing overcrowding in municipalities.

The model's efficacy is apparent through its successful application in the case study. It facilitates efficient control of tourist influx at designated spots, all the while minimizing the strain on the local cultural heritage and environment, as aligned with the scheduled itinerary of guided tours.

For the project's future advancement, several unresolved matters warrant investigation. The foremost pertains to the intricacy linked to the *TEN* dimension. Future research should encompass testing the model with an increased count of guided tours and available transportation services. To this end, a dedicated algorithm should be devised for automatically generating the *TEN*, aligning tourist demand with their specific parameters. Consequently, the second aspect involves enhancing the heuristic approach's precision by refining the constraints that permit deviations from the planned visit duration.

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