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**A LARGE NEIGHBORHOOD SEARCH BASED  
MATHEURISTIC FOR THE TOURIST CRUISES  
ITINERARY PLANNING**

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## **Abstract**

The planning of itineraries for tourist cruises is a complex process where several features, such as vessel selection, port services, and requirements for point of interests to be inserted in each tour, must be addressed. The present work models the tour planning problem as a variant of vehicle routing problem considering specific constraints such as: fixed number of tours, not mandatory visits of all nodes, multiple time windows, possibility to choose among different travel speed values. The resulting mathematical formulation lead to a complex model for which commercial solvers fail to solve large instances in a reasonable time. To overcome this issue we propose a Large Neighborhood Search based matheuristic, in which an over-constrained version of the mathematical model is used to exhaustively and efficiently explore large neighborhoods. Test results performed on a real case instances demonstrate effectiveness of the proposed approach.

*Key words:* rich vehicle routing; liner network design; matheuristics; Large Neighborhood Search; tourism management



## 1. Introduction

The business of tourist cruises itineraries requires companies to create different and appealing cruise tours which a convenient mix of visited locations in suitable time constraints and a balance of costs. Several decision parameters can affect the design of itineraries [3]. As stated in [2], the selection of attractive destinations is crucial process for a cruise company, but it has received a limited attention in the literature. One of the first attempts to address optimal cruise itineraries design has been reported in [13], where a mathematical model for cruises calls selection is proposed. [10] formulate an optimization for routing and scheduling vessels, given the set of ports to visit. This model has been applied to real data related to cruises starting from Florida and visiting Jamaica, Puerto Rico and Bahamas, while an application to coastal cruises in China has been discussed in [22]. Another crucial issue is the control of travel speed to reduce fuel consumption. The largest part of vehicle routing problems assume fixed speed along arcs, but, reducing cruise speed, when it is not necessary to maintain the maximum speed to respect time constraints, yield to a significant cost reduction [16]. Several applications in maritime logistics and ship routing consider speed as a decision variable. Speed reduction could have not only an impact from the economic point of view, but also from the environmental one, as pointed out in [20] and [6]. Tramp ship routing and scheduling optimization with variable speed has been addressed in [15] and [21]. The impact of carbon emissions taxation on ship travel speed decision has been analyzed in [19]. Speed optimization has been also considered in some green logistic applications, in which the objective is to reduce pollution, such as the Pollution Routing Problem (PRP), introduced by [4] and its Time Dependent version presented in [7]. Although speed optimization has become a hot topic in the last years for freight transportation, to our knowledge, no application has been presented on passengers transportation.

Several researches analyzed the network design of liner services, mostly applied in the shipment industry. In the present work we formulate the problem as a variant of vehicle routing with profits for an application to the tourism industry. Moreover, we compare in a real case application the performance of the exact approach with a Large Neighborhood Search (LNS) based Matheuristics which exploits some peculiarities of the formulation. Literature addressed the solution approach in different ways. In fact, the operation of liner services is a complex activity which require several interconnected design and planning decisions which may be coupled in several ways. Some researchers investigate design, planning and operation of linear services both in commercial and in tourist industry. Liner services are well described in [9] where cruise liner can be deployed for different tours having different lengths with re-positioning operations and crew scheduling to be solved on several class of job operators. The crew scheduling problem is formulated as an extensive Mixed Integer Linear Problem (MILP). The presented real case test instances can be solved by a commercial solver and test results highlight the decision support capability of MILP models. The service network design is investigated by [11]. Differently by our works where cruise liners are analyzed, [11] propose a optimization model for containerized shipment with the aim to minimize empty container re-positioning. The developed model is tested on realistic instances composed by 22 ports which can be managed by commercial solvers. In [8], the design of deep sea liner shipping is considered. This problem can be configured as a design of hub and spoke network for ocean container shipping. In these settings the resulting MILP model is challenging even for small instances. Thus, a decomposition approach is taken. [17] solve the liner shipping design network with an exact approach based on branch and cut. The described liner design network problem is similar to Vehicle Routing Problem with Time Windows (VRPTW) with several specific features such as “butterfly” routes and transshipment which are exploited in the cut

generation. A metaheuristic approach is proposed by [5] for the same problem defined as Liner Service Network Design Problem (LSNDP). Differently from standard VRP problems LSNDP are characterized by not fixed sources and destinations and can be multicommodity. [5] propose a model based metaheuristics where a mixed integer program is solved to identify insertions and removals of port calls from a single service and mathematical programming is indeed inserted into a Large Neighborhood Search based metaheuristics. In this work we will follow a similar approach. Metaheuristics are often used in Vehicle Routing based problems as evidenced by the survey of [1] where metaheuristics are defined as approaches where mathematical programming models are used in a heuristic framework. The authors classify the metaheuristic approaches in: *i) decomposition approaches*, where some or all of the subproblems are solved using mathematical programming models; *ii) improvement heuristics*, where mathematical programming models are used to improve a solution found by a different heuristics approach; *iii) Branch-and-price/column generation-based approaches*, where the exact method is modified to speed up the convergence.

As we can see, the application of liner network design to cruise industry is only partially covered by research literature. As noticed by [18], in cruise industry is critical to have a proper strategy oriented to itineraries and not destinations. In our paper we present a real problem where liner network design is applied to cruise industry. While the formulated model shares some similarities with the related shipping industry, several specific features are considered bringing in evidence the importance of itinerary planning.

## 2. The liner network design problem in the cruise industry

The problem hereafter presented has been specified in a case study related to a company operating cruises in the Mediterranean sea. In particular, a subset of the ports represented in the test instances are depicted in Figure 1. The cruise company is interested in designing appealing and diversified tours in order to meet customer demand. This “appealing” property is linked to the availability of different vessels with different sail capabilities. In the following of the paper we will define more formally the diversity of the designed tours by using the hamming distance. Another real case requirement associated at the Mediterranean use case is that vessels should be able to cover routes with different speeds; speed is a controllable variable both to let vessel to reach different destinations and for saving traveling and wait-at-ports related costs. With the respect to the available fleet, vessels have different speed capabilities while some of them, the largest ones, cannot serve some ports. Indeed, compatibility constraints among vessels and speed, and vessels and ports must be defined. Ports have several and different requirements. Some ports may require to be a fixed hop because are a “must” visit for tourists. In general, ports can be inserted in different itineraries. Therefore, contrary to what hold for vehicle routing or team orienteering problems, in this case tours can partially overlap. However, for logistic reasons, a constraint is imposed to avoid cruises visiting the same port in the same day. The planning horizon is then specified in term of hours. Ports may be visited in specific time window each day of the week. Time-windows specify the arrival and departure allowed times in order to let tourists to arrive in cities in suitable times (i.e. in the morning) and have enough time to visit the city. Therefore it is not allowed for the cruise to depart before a specified “service time”. Time-windows are different in departure ports, arrival ports, and other ports. Unit traveling cost depends by traveling distance and selected speed. A consistent share of the cost is represented by port taxes and time spent to wait to enter the port in order to meet a feasible time window. Port taxes can be interpreted as negative profits. Finally, the composition of the tour is constrained by a minimum number of port to be visited.

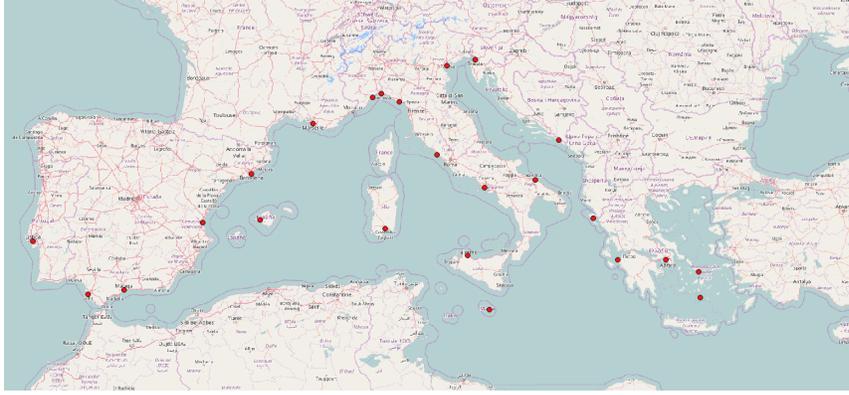


Figure 1: Map of available ports

### 3. Mathematical Formulation

The problem can be formulated on a graph  $G = (N, A)$  where  $N = I \cup D$  is the union of the available ports  $I$  and the set of starting and ending ports  $D$  for vessel (or cruise)  $k \in K$ .  $A$  is the set of oriented arcs connecting ports. For each cruise  $k \in K$  is possible to have different departure and arrival ports  $D_k^d, D_k^a$  with  $D^d = \bigcup_{k \in K} D_k^d, D^a = \bigcup_{k \in K} D_k^a, D = D^d \cup D^a$ . Other sets used in the formulation are the set of time intervals (days) of the planning horizon  $G$ , the set of vessel's speed  $S$ , and the set INCV of the unfeasible couples vessel - speed  $(k, s)$ . Model parameters and variables are listed in the following.

<i>Parameters</i>	
$\delta$	maximum number of visited nodes shared by two itineraries
$\gamma$	minimum number of stops for each itinerary
$Q_{min_i}$	minimum number of itineraries in which port $i$ must/can be visited
$Q_{max_i}$	maximum number of itineraries in which port $i$ must/can be visited
$ms_i$	minimum service time for port $i$
$c_{ijk}$	arc traveling cost
$st_{ik}$	service time required in port $i$ for vessel $k$
$dpre_i, dpost_i$	required service time before entering and after leaving the port $i$
$\epsilon, \text{BigM}_1, \text{BigM}_2$	enough small ( $\epsilon$ ) and big numbers
$CSV_{ik}, CF$	port and vessel costs
$CS_{ik}$	port service costs

#### *Variables*

6.

$x_{ijks} \in \{0, 1\}$	binary variable equal to 1 if vehicle $k$ travels arc $(i, j)$ with speed $s$ , 0 otherwise
$y_{ikg} \in \{0, 1\}$	equal to 1 if vehicle $k$ serves node $i$ in day $g$
$w_{ik} \in \mathbb{R}_{\geq 0}$	time of service start in node $i$ for vehicle $k$
$z_{ik} \in \mathbb{R}_{\geq 0}$	service time in node $i$ for vehicle $k$
$u_{ik} \in \{0, 1\}$	equal to 1 if port $i$ is visited by vehicle $k$ , 0 otherwise
$h_{ikk'} \in \{0, 1\}$	equal to 1 if port $i$ is visited by vehicles $k$ and $k'$

The model can be written as follows:

$$\begin{aligned} \min Z = & \sum_{(i,j) \in A} \sum_{k \in K} \sum_{s \in S} c_{ijks} x_{ijks} + \\ & \sum_{i \in I} \sum_{k \in K} \sum_{g \in G} [\text{CSV}_{ik} + \text{CF}] y_{ikg} + \sum_{i \in I} \sum_{k \in K} \text{CS}_{ik} z_{ik} \end{aligned} \quad (1)$$

subject to

$$\sum_{(i,j) \in A} \sum_{s \in S} x_{ijks} = \sum_{g \in G} y_{ikg} \quad i \in I, k \in K, i \notin D_k^D \quad (2)$$

$$\sum_{(i,j) \in A} \sum_{s \in V} x_{ijks} = \sum_{(j,i) \in A, s \in S} x_{jiks} \quad i \in I, k \in K, i \notin \{D_K^A, D_K^D\} \quad (3)$$

$$\sum_{(i,j) \in A} \sum_{s \in S} x_{ijks} = 1 \quad k \in K, i = D_K^D \quad (4)$$

$$\sum_{(i,j) \in A} \sum_{s \in S} x_{ijks} = 1 \quad k \in K, j = D_K^A \quad (5)$$

$$\sum_{i \in I} u_{ik} \geq \gamma \quad k \in K \quad (6)$$

$$\sum_{s \in S} x_{ijks} \leq 1 \quad (i, j) \in A, k \in K \quad (7)$$

$$\sum_{k \in K} y_{ikg} \leq 1 \quad g \in G, i \in I \setminus \{D_k^D, D_k^A\} \quad (8)$$

$$\text{ms}_i y_{ikg} \leq z_{ik} \quad i \in I, k \in K, g \in G \quad (9)$$

$$x_{ijkv} = 0 \quad (k, s) \in \text{INCV} \quad (10)$$

$$w_{ik} \leq 24(g+1) - 10 + (1 - y_{ikg}) \text{BigM}_1 \quad i \in I \setminus \{D_k\}, g \in G, k \in K \quad (11)$$

$$w_{ik} \leq 24g + 12 + (1 - y_{ikg}) \text{BigM}_1 \quad k \in K, i = D_k^A \quad (12)$$

$$\begin{aligned} w_{ik} \geq & 24g + 16 - \text{st}_{ik} - z_{ik} \\ & - (1 - y_{ikg}) \text{BigM}_1 \quad k \in K, i \in I \setminus \{D_k^D, D_k^A\} \end{aligned} \quad (13)$$

$$w_{ik} + z_{ik} + \text{dpre}_i + \text{dpost}_j + \sum_{v \in V} t_{ijkv} x_{ijkv} - w_{jk} \leq (1 - \sum_{s \in S} x_{ijkv}) \text{BigM}_2 \quad (i, j) \in A, k \in K \quad (14)$$

$$z_{ik} + (1 - \sum_{s \in S} x_{ijkv}) \text{BigM}_2 + (1 - \sum_{s \in S} t_{ijkv} x_{ijkv}) + \text{st}_{ik} \geq w_{jk} - w_{ik} \quad (i, j) \in A, k \in K \quad (15)$$

$$Q_{\min_i} \leq \sum_{k \in K} u_{ik} \leq Q_{\max_i} \quad \forall i \in I \quad (16)$$

$$\sum_{i \in I} h_{ik'k''} \leq \delta \quad \forall i \in I, k' \in K, k'' \in K \quad (17)$$

$$h_{ik'k''} \leq \frac{1}{2}(u_{ik'} + u_{ik''}) \quad \forall i \in I, k' \in K, k'' \in K \quad (18)$$

$$h_{ik'k''} \geq u_{ik'} + u_{ik''} - 1 \quad \forall i \in I, k' \in K, k'' \in K \quad (19)$$

$$\left( \sum_{g \in G} y_{ikg} \right) \epsilon \leq u_{ik} \leq \sum_{g \in G} y_{ikg} \quad \forall i \in I, k \in K \quad (20)$$

$$\sum_{j \in I} \sum_{s \in S} x_{ijkv} \leq \sum_{g \in G} y_{ikg} \quad \forall i \in I, k \in K \quad (21)$$

The objective function is expressed in (1). Constraint (2) implies the following: if a port  $j$  is served, then a link  $(i, j)$  is traversed from a vehicle  $k$ , with a speed set to  $s$ . Constraint (3) implies that traveled arcs entering a node must be equal in number to the traveled arcs exiting a node for each vehicle  $k$ , except the departing and arrival depot of the vehicle. Constraints (4) and (5) impose that vehicles must depart from the its departing port and arrive to its arrival port. (6) impose a number of visit for each vehicle greater or equal than  $\gamma$ . Constraint (7) allows one speed for each traveled arc. Constraint (8) disable the visit of a same port for two vehicles in the same day. (9) bounds the service time on a port to the minimum required service time. Constraint (11) defines the right side arrival time windows for ports Constraint (12) define right side time windows for arrival depots. Constraint (13) defines arrival time window for ports. Constraints (14) and (15) define the arrival time variables. Constraint (16) bounds the number of visits for each port  $i$  between a mininum  $Q_{\min_i}$  and a maximum  $Q_{\max_i}$  (17) limit the number of common nodes visited by each vehicle.

#### 4. Solution approach

The model represented is a complex VRP with profits, heterogeneous fleet, multiple time windows, multiple visits, and specific requirements. An important consideration, in the specific application case, is that time constraints make the problem easier to be solved because they reduce the solutions space. Moreover, higher values of  $\delta$  help to simplify the problem. With  $\delta = \gamma = Q_{\max}$  the problem becomes a TSP with profit, with a limited number of stops). In contrast, higher  $Q_{\max}$  values make the problem harder to solve. With  $Q_{\max_i} = 1$  for all the nodes, the problem becomes a VRP with profit, while with  $Q_{\max_i} = Q_{\min_i} = 1$  for all the nodes, the problem becomes a standard VRP.

To solve the problem, we propose a Large Neighborhood Search (LNS) based Matheuristic, effectively used in similar contexts [12, 5, 1, 14], in which several neighborhoods, generated by

ad-hoc defined destroy operators, have been implemented. The Large Neighborhood Search is exploited directly by the model. In this way, it is possible to obtain the local minimum with respect to the considered neighborhood, within a very small computational time. Real time performance analysis of the destroy operators let to dynamically tune their selection criteria, such as exploited in [14].

#### 4.1. A Large Neighborhood Search Matheuristic for the Tourist Cruises Itinerary Planning

The algorithm we propose starts from a feasible initial solution which could be obtained in different ways. The quality of the initial solution is not a crucial issue because, even starting from a bad solution, the method is capable to quickly converge towards high quality solutions. For this reason we decided to compute an initial solution running the model with a short time-limit  $TL$ , imposing that each node can be visited at most once, ( $Qfix_i = 1$ ) and limiting the number of nodes that can be selected to  $Nmax_i$ s. These two parameters should be chosen in order to be capable to find a feasible solution within a reasonable computational time. The best solution obtained is then used as initial solution. At each iteration of the algorithm, given a current solution  $CS$ , we define, for each port  $i$  and vessel  $k$ , a constant  $Ufix_{ik}$  which take value equal to 1 if, in  $CS$ , node  $i$  is visited by vessel  $k$  and 0 otherwise. Then we randomly select  $P_{max}$  nodes and store them into the set  $P$ . For all the nodes which do not belong to  $P$ , we fix all the variables  $u_{ik} = Ufix_{ik}$ , i.e. if the nodes were selected in  $CS$ , we force them to be visited by the same vessel as in  $CS$ , otherwise, if they were not be selected, we forbid to select them. Instead, all the nodes belonging to  $P$ , are let free to be selected or not and to be assigned to any vessel. Furthermore, if a node  $i$  was selected in  $CS$  we increase of one unit the maximum number of times it can be visited, up to the maximum number of allowed visits is reached,  $Qfix_i = \max(Qfix_i, Qmax_i)$ . If  $i$  were not selected in  $CS$  we fix  $Qfix_i = 1$ . Then, we solve the resulting over-constrained version of the model with a short time-limit  $TL$  and keep the best solution obtained  $S_{new}$ . If this solution is better than the current solution  $CS$ , we save  $S_{new}$  as the new current solution. This procedure terminates if a maximum number of iterations without improvement, *maximprove*, is reached or after a maximum number of iterations, *maxiter*. The pseudo-code of this algorithm is reported in Algorithm 1. The great advantage of this matheuristic respect to classical metaheuristics is that we can explore large neighborhoods, in a short computational time, exploiting the mathematical model. In this way, we are able to overcome local minima and large infeasibility regions in which classical methods remain trapped; this is true especially for rich high constrained VRPs in which the number of feasible solutions is quite limited and they are widespread across the solutions space which is characterized by frequent and large infeasibility *holes*.

Some considerations should be made about how to detail the algorithm sketched in 1. We could had worked on larger neighborhoods without fixing the assignment to a vessel, but only the presence in the solution  $Ufix_i$ . We could had worked on smaller neighborhoods fixing directly the variable  $y_{ikg}$ . In the first case the neighborhood is too large and it would take too much time to find a feasible solution while in the second case the neighborhood is too small and we risk to remain trapped into a local minimum.

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**Algorithm 1** Matheuristic scheme for cruise liner design problem
 

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- 1: **Initialization:** Let  $iter = 0, itimprove = 0, maxiter$  maximum number of iterations,  $maximprove$  max number of iterations without improvement,  $TL$  the time limit. Set  $Ufix_{ik} = 1$  if node  $i$  was visited by vessel  $k$ , 0 otherwise;  $Qfix_i$  max number of allowed visits for node  $i$
  - 2: **Initial heuristic solution:** Run the model on a over-constrained setting where only a limited number of nodes are allowed to be visited.
  - 3: **while**  $iter \leq maxiter$  **and**  $itimprove \leq maximprove$  **and**  $time \leq tlimit$  **do**
  - 4:   Randomly select a number of vertices  $P_{max}$  and keep them in a pool  $k$ .
  - 5:   For all vertices  $i \notin P$  force  $u_{ik} = Ufix_{ik}$  while for all vertices  $i \in P$  let  $u_{ik}$  free
  - 6:   set  $Qfix_{i+} = 1, Qfix_i = \max(Qfix_i; Qmax_i)$  for all visited vertices in best solution and  $Qfix_i = 1$  for the others
  - 7:   Run the resulting over-constrained model with time limit  $TL$  and eventually update the best found solution
- 

## 5. Results

The described algorithm approach is designed to be effective in the over-constrained real instance of cruise liner design network problem. We have tested the algorithm on real data obtained from a cruise company.

In particular, in the case analyzed the settings are:

- number of ports: 49
- number of ships (vessels): 4
- number of planning days (time horizon): 7.
- number of allowed speeds 5, with  $S \in \{10, 11.5, 13, 20, 23\}$ [Mph]
- number of arcs: 445;
- number of routes (available tuples  $i, j, k, v$ ): 8900

Starting with this data we have generated 4 sets of 9 instances with different associated values of  $Q_{min}$  and  $Q_{max}$ . In Set 1 we consider  $Q_{min}=0$  and  $Q_{max}=2$ , in Set 2,  $Q_{min}=0$  and  $Q_{max}=3$ , in Set 3,  $Q_{min}=0$  and  $Q_{max}=4$  while in Set 4 we consider  $Q_{min}=1$  for some nodes and  $Q_{min}=0$  for the others, while  $Q_{max}=4$  for all the nodes. Other dimensions of analysis are the use of different values for the maximum number of ports shared between two routes,  $\delta = 1, 2, 3$  and for the minimum number of stops per route,  $\gamma = 4, 5, 6$ . Each instance of each set is associated with a different combination of the parameters  $\delta$  and  $\gamma$ . The model has been run with Xpress 7.9 on a i7 5500U with 16 GB of Ram, with a time-limit of 3600 s. The matheuristic has been run on the same machine with the following parameters:

- initial solution time limit: 20 s with  $Q_{fix} = 2$  and 40 pre-selected ports
- $P_{max} = 5$
- $maxiter = 100$

Table 1: Results for solver,  $Q_{max} = 2$ 

INSTANCE	DELTA	GAMMA	UB	LB	GAP	TIME
I1	1	4	293.23	250.206	17.20%	3600
I2	1	5	381.13	299.96	27.06%	3600
I3	1	6	497.98	388.577	28.15%	3600
I4	2	4	280.86	271.921	3.29%	3600
I5	2	5	370.04	313.766	17.93%	3600
I6	2	6	470.80	404.775	16.31%	3600
I7	3	4	280.86	262.199	7.12%	3600
I8	3	5	364.55	340.671	7.01%	3600
I9	3	6	463.61	399.182	16.14%	3600

Table 2: Results for solver,  $Q_{max} = 3$ 

INSTANCE	DELTA	GAMMA	UB	LB	GAP	TIME
I1	1	4	288.51	238.03	21.21%	3600
I2	1	5	383.06	322.81	18.66%	3600
I3	1	6	499.58	418.90	19.26%	3600
I4	2	4	273.22	254.11	7.52%	3600
I5	2	5	363.75	308.40	17.95%	3600
I6	2	6	461.30	378.89	21.75%	3600
I7	3	4	272.36	258.87	5.21%	3600
I8	3	5	347.05	342.13	1.44%	3600
I9	3	6	442.01	409.56	7.92%	3600

- $maximprove = 5$ ,
- $tlimit = 20sec$ .

The matheuristic has been implemented and run under Xpress 7.9. In tables 1-4 we report results obtained with the model. More in details, we report the best solution obtained within the time-limit (UB), the best lower bound (LB), the percentage gap between UB and LB and the computational time. As it can be evinced from the tables, the model is not able to close any instance to the optimally within the time-limit, with a global average gap of 14.43%. Results are homogeneous across the 4 sets. In tables 5-8 we compare the results obtained by the model with those obtained with the matheuristic. We report the best UB obtained by the model, the best UB obtained by the matheuristic over 10 runs, and the average UB obtained by the matheuristic. Computational times requested by the matheuristic are much smaller than those requested by the model (on average: 225 s against 3600 s). The best UB obtained, is almost always better than the best UB found by the model, (0.34%), and the average UB is only 1.85%. This means that the algorithm is robust, efficient, and effective in solving this problem.

## 6. Conclusion

In this paper we addressed the problem, faced by cruise companies, to design an attractive cruise itineraries portfolio. Although this process represents a crucial issue in the cruise tourism industry, it has received a limited attention from the academic community. The process of

Table 3: Results for solver,  $Q_{max} = 4$ 

INSTANCE	DELTA	GAMMA	UB	LB	GAP	TIME
I1	1	4	288.51	234.93	22.81%	3600
I2	1	5	382.65	331.27	15.51%	3600
I3	1	6	497.98	414.29	20.20%	3600
I4	2	4	270.88	251.01	7.92%	3600
I5	2	5	361.20	285.74	26.41%	3600
I6	2	6	462.33	377.26	22.55%	3600
I7	3	4	270.29	257.45	4.99%	3600
I8	3	5	345.40	334.50	3.26%	3600
I9	3	6	442.93	386.01	14.75%	36

Table 4: Results for solver,  $Q_{min} = 1$  (for 5 nodes,  $Q_{max} = 4$  for all)

INSTANCE	DELTA	GAMMA	UB	LB	GAP	TIME
I1	1	4	288.51	243.622	18.4%	3600
I2	1	5	379.70	317.209	19.7%	3600
I3	1	6	498.57	401.47	24.2%	3600
I4	2	4	271.16	261.675	3.6%	3600
I5	2	5	361.43	327.934	10.2%	3600
I6	2	6	464.15	394.733	17.6%	3600
I7	3	4	270.29	257.754	4.9%	3600
I8	3	5	345.40	309.942	11.4%	3600
I9	3	6	444.52	404.905	9.8%	3600

Table 5: Results for LNS,  $Q_{max} = 2$ 

INSTANCE	MODEL	LNS-BEST	LNS-AVG	TIME(s)	FOUND(s)
I1	293.23	<b>290.68</b>	292.99	222.33	178.96
I2	381.13	381.13	385.40	139.10	81.39
I3	497.98	<b>494.74</b>	505.07	250.91	189.78
I4	280.86	280.86	285.91	155.94	103.93
I5	370.04	<b>369.52</b>	376.31	267.50	207.58
I6	470.80	<b>469.99</b>	479.78	253.43	184.91
I7	280.86	280.86	284.71	227.98	170.74
I8	364.55	364.55	370.42	324.57	256.36
I9	463.61	<b>453.67</b>	465.59	355.33	287.92
mean	378.12	376.22	382.91	244.12	184.62

Table 6: Results for LNS,  $Q_{max} = 3$ 

INSTANCE	MODEL	LNS-BEST	LNS-AVG	TIME(s)	FOUND(s)
I1	288.51	288.51	293.12	174.95	120.81
I2	383.06	385.26	386.93	139.10	81.39
I3	499.58	<b>491.56</b>	501.07	278.79	218.59
I4	273.22	273.22	276.46	145.52	96.17
I5	363.75	364.92	369.15	265.35	210.10
I6	461.30	461.61	466.93	215.46	156.72
I7	272.36	272.36	277.67	196.99	143.87
I8	347.05	349.49	354.06	259.72	208.99
I9	442.01	<b>433.51</b>	443.84	422.24	365.17
mean	370.09	368.94	374.36	233.12	177.98

Table 7: Results for LNS,  $Q_{max} = 4$ 

INSTANCE	MODEL	LNS-BEST	LNS-AVG	TIME(s)	FOUND(s)
I1	288.51	288.51	291.09	159.80	108.14
I2	382.65	386.04	388.68	115.10	62.22
I3	497.98	<b>493.67</b>	504.62	224.89	162.45
I4	270.88	273.22	276.49	207.25	159.84
I5	361.20	362.96	368.62	222.56	169.35
I6	462.33	<b>459.76</b>	468.63	246.54	185.61
I7	270.29	273.19	280.96	143.01	95.92
I8	345.40	349.10	363.78	180.59	130.83
I9	442.93	<b>437.66</b>	445.42	292.37	237.
mean	369.13	369.35	376.48	199.12	145.76

Table 8: Results for LNS,  $Q_{min} = 1$  (for 5 nodes,  $Q_{max} = 4$  for all)

INSTANCE	MODEL	LNS-BEST	LNS-AVG	TIME(s)	FOUND(s)
I1	288.51	288.51	293.68	136.42	82.00
I2	379.70	380.33	386.94	135.03	79.57
I3	498.57	<b>490.4</b>	501.30	242.40	183.25
I4	271.16	271.27	275.69	177.36	125.93
I5	361.43	360.74	374.33	215.03	159.78
I6	464.15	<b>460.02</b>	470.46	251.69	191.20
I7	270.29	270.44	273.34	185.04	137.09
I8	345.40	345.61	354.20	209.61	156.19
I9	444.52	<b>435.69</b>	446.58	351.04	292.22
mean	369.30	367.00	375.17	211.51.	156.36

ship itinerary planning for tourist cruises must take into account several features related to vessel selection, port services, and specific requirements for point of interests to be inserted in each tour, such as the minimum visiting time required, the attractiveness of the location and the port costs. The present work models the tour planning problem as a rich vehicle routing problem considering specific constraints such as: fixed number of tours, not mandatory visits of all nodes, allowed multiple non overlapping visits to the same node by different tours, variety of the offer, i.e. minimum degree of diversity among tours to be respected, multiple time windows and possibility to choose among different cruise travel speeds. We proposed a mixed integer programming model to minimize operational costs while respecting given constraints, and an effective and efficient Large Neighborhood Search Matheuristic. The great advantage of this matheuristic, with the respect to classical metaheuristics, is that we can explore very large (exponential) neighborhoods in a short computational time, exploiting the mathematical model. In this way, we are able to overcome local minima and large infeasibility regions in which classical method generally remain trapped, especially for rich high constrained VRPs in which the number of feasible solutions is quite limited and they are widespread across the solutions space which is characterized by frequent and large infeasibility *holes*. The proposed method is suitable to solve all rich vehicle routing problems, arising in real applications, suffering of this *infeasibility* aspect, in solving which generally standard methods fail.

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