THE ANALYSIS OF FERRY PASSENGER TRANSPORTATION DEMANDS

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ABSTRACT

We analyze the variations in the ferry passenger transportation demands for an observed period in the case of the Boka Kotorska Bay (located in Montenegro). The region is well known for this kind of transport offered to satisfy touristic purposes during the summer season. Besides different approaches to increase the operating efficiency of ferry operators, we concentrate on the definition of transport planning and optimization of fleet size engaged for passengers during the considered time-frame. Although reviewing various schemes of ferry transportation, we introduce the mixed-integer linear programming (MILP) model to examine several numerical examples of private ferry operators and the application of a commercial CPLEX solver for solving the ferry fleet optimization problem. After the analysis, we propose the scenario for establishing partnership between small operators that forms a joint ferry operator with an aim to increase the profit of all partners. The research proposes future directions in sustainable ferry service development, including the uncertainty in the transportation demands caused by unexpected circumstances such as the COVID-19 pandemic.

Keywords: size of ferry fleet, route planning, variation in demands, tourists visits

1. INTRODUCTION AND BACKGROUND

When modeling transportation problems and defining the optimal size of the fleet (resources), there is a need to provide adequate transport capacity to meet required transportation demands. Discrepancies between transport capacities and unpredictable transport demands occur when the demands are not known in advance or are exposed to some uncertain aspects due to variations caused by seasonality, the level of transport prices, technical solutions, system failures, etc. For this reason, the stochasticity of particular transport processes has been largely discussed in the scientific literature, while several studies have been reported at the passenger ferry level [1, 9, 14, 15].

In some cases, due to the uncertainty of the transport demands, there are situations when the capacity of the passenger ferry fleet is not sufficient to meet the transport demands in the considered time interval. Inadequate response in terms of providing transport capacity toward transport demands motivates the ferry operator to develop an appropriate strategy for planning capacity and structure of the fleet. Accordingly, the options for purchasing or chartering-in capacity need to be considered. These are decisions about buying or hiring an additional fleet that come to the fore when there is the increase in some parameters such as the demands for transportation, the traffic volume, etc. As mentioned earlier, the decisions are strategic, because they indicate the possibility of defining the structure of the ferry fleet in a long time and reflect the aspect of the uncertainty of parameters [14].

The ship fleet sizing problem has been studied extensively in the previous period. The general strategic problems in shipping facing with the assignment level of the new fleet for the transport tasks have been investigated in [2]. The concept of user equilibrium was formulated as a linear programming model. The ship fleet employment process using mixed-integer linear programming was defined in [10]. The author investigated the transportation demands containing uncertainty described by probability distributions. Moreover, a numerical analysis to solve the container ship employment with the anticipated demand was used. The author tested the stochastic dependence in several numerical examples as shown in [11].

On the other hand, observing routing problems, the methodology for optimal routing in liner shipping service considering the ship fleet sizing was proposed in [3]. A ferry company strategy based on the traffic flow schedule providing the overall service economic benefit was introduced in [16]. A detailed review of the literature regarding the sizing of the fleet of ships used in maritime transport was reported in [12]. In the analysis, they included different optimization problems related to the fleet capacity and required transport demands.

Referring to the ferry fleet optimization, a ferry network design problem integrating three different but complementary aspects: the optimal fleet size, routing, and scheduling for both direct and multi-stop services was presented in [7]. The authors developed a heuristic algorithm that exploits the polynomial-time performance of shortest path algorithms in the case of the Port of Hong Kong. A formulation for ferry service network design with stochastic demands via the notion of service reliability was developed in [9]. The results of the used method led to substantial cost savings compared to deterministic methods under demand uncertainty. The method for the ferry service network design in the Port of Hong Kong, assuming that the demand is a stochastic component was proposed in [1]. The authors formulated the problem as a two-phase stochastic program. A Service Reliability-based gradient solution approach was used.

For providing the economic benefits resulting in making strategic decisions for ferry services sustainability, the feedback on how users value the quality attributes of ferry routes serving long distance traffic was shown in [8]. These contributions are reached through the users' preference survey in the case of two strategic ferry routes. On the other hand, a modified exponential demand function to calculate user and social surplus for 97 ferry services in Norway was used in [6]. The authors concluded that a positive social surplus can be achieved even though the operators need subsides. The transportation systems that include the waiting time for vehicles and passengers to board a ferry were observed. In the paper, the psychological implications of the position in the queue and average waiting time that impact the information between passengers are given in [4].

A recent study on the passenger ferry fleet sizing was reported by Škurić et al. [13]. The authors investigated the optimal allocation of the ferry fleet along routes in the Boka Kotorska Bay (Montenegro) by defining a mixed-integer linear programming (MILP) model for the maximization of ferry operator's profit. The problem was solved with an exact CPLEX solver, while the authors used three MILP-based heuristics in the case of hard numerical examples. In the model formulation, they included the transportation demands on routes for local inhabitants and tourists and the option for using ferries of existing, purchased, and chartered-in fleets. Similar to [13], in this paper, we deal with the touristic routes only and propose the new scenario for establishing a joint ferry operator (a result of the small operators partnership) in the engaged fleet structure to maximize the profit in a two-year time.

The paper is structured as follows. Section 2 explains the details of demands and considered routes in the case of tourists' transportation in the Boka Kotorska Bay (Montenegro) in the years 2018 and 2019. The model formulation to maximize the profit of ferry operators is given in Section 3. Section 4 contains the results and a new scenario for defining the ferry fleet structure to provide increase in the profit for a joint company (operator) consisted of small operator partnerships. Final recommendations are provided in Section 5.

2. PASSENGER FERRY DEMANDS ANALYSIS

Here we analyze the average monthly tourists' demands in 2018 and 2019 achieved at four routes in the Boka Kotorska Bay.

The considered routes are [14]:

- Route 1: Perast – Our Lady of the Rocks – Perast.
- Route 2: Kotor – Herceg Novi – Our Lady of the Rocks – Perast – Kotor.
- Route 3: Kotor – Our Lady of the Rocks – Perast – Kotor.
- Route 4: Cruise cycling along the Bay.

Each route was operated by different small private operators. The observed period for each route is from March to November, even though there were no demands for transportation of tourists at Routes 2 and 4 in March and November. As there was no traffic in January, February, and December, we did not consider the whole year period. The average monthly tourist demands for Route 1 are presented in Figure 1. As it can be noticed, a bigger average throughput was achieved in 2019 (67 tourists compared to 59 in 2018 [14]), especially in May, June, and July. One ferry of 55 passenger capacity (f1) realized the whole transport. Sometimes in the summer season, the ferry made two or three calls to the ports [14].

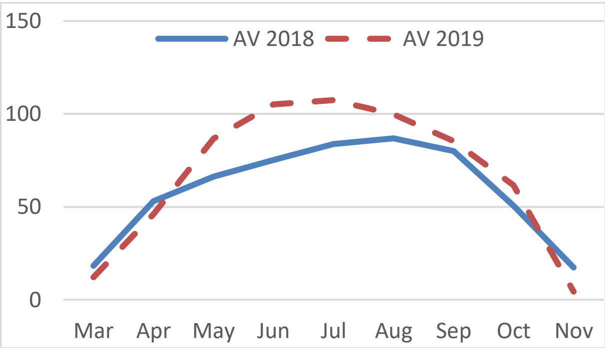

Figure 1: Average monthly passenger demands for Route 1 [14]

Looking at Route 2, the average monthly tourists' demands are shown in Figure 2. The transportation was realized by one ferry of 55 passenger capacity (f2). This route generally characterizes only one ferry's departure from and arrival to Kotor daily. The average passenger throughput in 2018 was 19, while in 2019 was 23 [14].

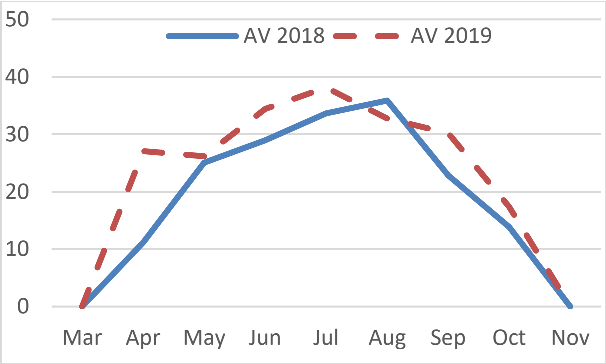

Figure 2: Average monthly passenger demands for Route 2 [14]

The average monthly passenger demands for Route 3 are given in Figure 3. This short route was served with the ferry of 55 passenger capacity operating once or twice a day (f3). Obviously, from the statistics, there was a similar average passenger throughput in 2018 (of 24 tourists per day) and 2019 (of 26 tourists per day) [14].

A ferry of 400 passenger capacity (f4) was engaged for tourists' transportation along Route 4 (see Figure 4). This route is familiar for the whole bay cruise cycling from April to October. The average daily transport demand with two stops in 2018 was 90 tourists, while the statistics increased in 2019 and amounted to 111. There was a higher increase from June to September where the ferry operated twice or three times in a day than occasionally but without total capacity used [14].

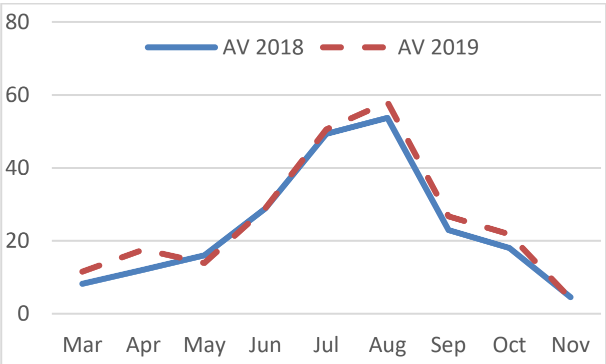

Figure 3: Average monthly passenger demands for Route 3 [14]

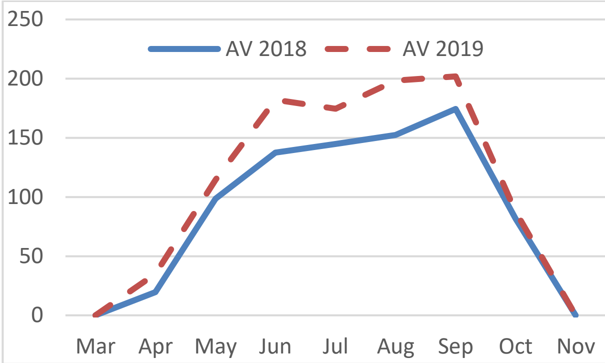

Figure 4: Average monthly passenger demands for Route 4 [14]

The data presented in the section are used for testing the mathematical model developed for maximization of the operator's profit in the case of changing the fleet structure.

3. MODEL DECRIPTION

MILP problems involve maximizing or minimizing a linear function with the existence of the appropriate constraints that apply to some of the variables in the model. The MILP problem can generally be presented as [5]:

$$\min \sum_{j=1}^{n} c_j x_j \qquad (1)$$

s.t.

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad \forall i \in M = \{1,2,\ldots,m\}$$

$$x_j \in \{0,1\}, \qquad \forall j \in \mathcal{B}$$

$$x_j \geq 0, \qquad \forall j \in \mathcal{G}$$

$$x_j \geq 0, \qquad \forall j \in \mathcal{C}$$

where the set $\boldsymbol{N} = \{\boldsymbol{1}, \boldsymbol{2}, \ldots, \boldsymbol{n}\}$ is divided into three subsets $\boldsymbol{\mathcal{B}}$, $\boldsymbol{\mathcal{G}}$, and $\boldsymbol{\mathcal{C}}$ corresponding to binary, integer and continuous variables, respectively.

In our case, the objective, eq. (2), is to maximize the profit (P) of the ferry operator. The profit is calculated as the difference between the revenues and the costs. The components of the objective function are grouped as follows:

$$P = EFT + PF + CF - ICP - ICC - PCL - PCT \qquad (2)$$

with

EFT – the income and cost difference of tourists transportation with the ferries of existing fleet in $;

PF – the income and cost difference of tourists transportation with the ferries of purchased fleet in $;

CF – the income and cost difference of tourists transportation with the ferries of chartered-in fleet in $;

ICP – costs on idle time of purchased ferry in $;

ICC – costs on idle time of chartered-in ferry in $;

PCL – costs on unused seats on board purchased ferry in $;

PCT – costs on unused seats on board chartered-in ferry in $.

Tourists can be transported by all types of ferries in the fleet (existing, purchased and hired). For details on model formulation, parameters, and constraints, see [13, 14]. The generated numerical examples are simplified here since the touristic routes are only considered in the analysis. However, the analysis provided in the next Section contains the comparison of two outputs: the generated profit and the number of unused seats on board ferries. The CPLEX MIP exact solver version 12.6 was used to solve the numerical examples.

4. RESULTS

From the statistics presented in Section 2, we identify that the level of utilization of the ferries' transport capacity is:

- 2018: 56% (f1), 38% (f2), 30% (f3), and 25% (f4).
- 2019: 56% (f1), 50% (f2), 35% (f3) and 30% (f4).

The total profit of the operators for observed 9-month-period of both 2018 and 2019, respectively, is presented in Tables 1 and 2. The real profit of four ferries is given in the second column of Tables 1 and 2.

Based on the low capacity utilization of each ferry and policy to service one route only, we analyze the possibility for available ferries to be assigned to all four routes. The result of the modeled profit, calculated by eq. (2) is presented in the third column of Tables 1 and 2. Unlike real examples (of assigned ferry f1 to Route 1, ferry f2 to Route 2, ferry f3 to Route 3, and ferry f4 to Route 4), in Tables 1 and 2 the allocation of available ferries in the fourth column are given.

Table 1: Real and profit generated by CPLEX solver for transportation demands in 2018 [14]

	Real profit ($)	Modeled profit ($)	Engaged ferry (CPLEX)
March	1652	2448.5	f1, f2, f3
April	22953	24332	f1, f2, f3
May	70552	102428	f1, f2, f3, f4
June	88796	120954	f1, f2, f3, f4
July	102229	119136	f1, f2, f3, f4
August	107688	158107	f1, f2, f3, f4
September	102562	114028	f1, f2, f3, f4
October	54839	70746	f1, f2, f3
November	3693	3716.5	f1, f2, f3
Total	554964	715896	f1, f2, f3, f4

Table 2: Real and profit generated by CPLEX solver for transportation demands in 2019 [14]

	Real profit ($)	Modeled profit ($)	Engaged ferry (CPLEX)
March	7139	10954	f1, f2, f3
April	35006	45859	f1, f2, f3, f4
May	80868	94537	f1, f2, f3, f4
June	115047	150253	f1, f2, f3, f4
July	122971	148619	f1, f2, f3, f4
August	131619	175911	f1, f2, f3, f4
September	119108	150787	f1, f2, f3, f4
October	59662	78113	f1, f2, f3, f4
November	1652	5515	f1
Total	673072	860548	f1, f2, f3, f4

The total profit both in 2018 and 2019 would increase from 1228036 $ to 1576444 $. In 2018, ferry f4 realized a smaller number of voyages with respect to other ferries, while the majority of transport demands for Route 4 was realized by ferries f1, f2, and f3. However, according to the results provided by CPLEX solver, ferry f4 was engaged only from May to September. A similar situation happened in 2019, and results indicate that ferry f4 was engaged more than in 2018 due to the increased demands from April to October. In all cases of the monthly examples in 2018 and 2019, the CPLEX solver got the optimal solutions easily within the short CPU time [14]. As can be seen from the presented results, pure rearrangement of ferries leads to the increase in the operators' profit. However, we went even further in our analysis proposing the modification of the ferry fleet for the additional profit increase. The obtained results are described in the remainder of this section.

4.1. New fleet scenario analysis

If we assume that the private operators establish a joint company for the ferry transport in the bay along four routes starting with the four ferries given in Sections 2 and 4 (f1, f2, f3, and f4), the joint operator can consider different strategy and purchase or charter-in additional ferries to maximize the total profit. For example, if we assume that there are available ferries to be purchased at the market [14]:

- ferry f5 with the capacity of 12 passengers;
- ferry f6 with 24 passengers;
- ferry f7 available to transport 55 passengers;
- ferry f8 available to transport 70 passengers;
- ferry f9 with 150 passengers;
- ferry f10 with the capacity of 200 passengers.

On the other hand, at the market there are available ferries to be chartered-in [14]:

- ferry f11 with the capacity of 12 passengers;
- ferry f12 with 24 passengers;
- ferry f13 available to transport 55 passengers;
- ferry f14 available to transport 70 passengers;
- ferry f15 with 150 passengers;

- ferry f16 with the capacity of 200 passengers.

Applying the MILP model, the results of the new scenario in the profit maximization and number of unused seats on board ferries obtained by the CPLEX solver are given in Tables 3 and 4.

Table 3: Results of new scenario for 2018 [14]

	New profit ($)	Unused seats	Fleet structure
March	6548	643	f1, f2, f3, f11
April	30484.5	702	f1, f2, f3, f12
May	112266	1091	f1, f2, f3, f11, f12
June	113276	813	f1, f2, f3, f11, f12
July	191286.5	1473	f1, f2, f3, f5, f11, f12
August	197635	1456	f1, f2, f3, f4, f5, f11, f12
September	107635	1092	f1, f2, f3, f4, f11, f12
October	99004.5	1263	f1, f2, f3, f11, f12
November	9878	460	f1, f2, f3, f11
Total	868013.5	8993	f1, f2, f3, f4, f5, f11, f12

As it can be seen, the achieved profit for the analyzed two seasons (2018 and 2019) would increase to 1635385.5 $ compared with 1228036 $ in the real-life case realized by only 4 ferries, f1, f2, f3, and f4. In the new scenario, the fleet would include ferries f1, f2, f3, f4, f5, f11, and f12. The joint operator would purchase ferry f5 and charter-in ferries f11 and f12. The total number of unused seats is 15216, as the required total number of transported tourists is 116051. The results from Tables 3 and 4 are also the consequence of the more intensive engagement of smaller ferries in comparison with the bigger ones, while the later are used more for the increased daily transport demands. In 2018, the results indicate that operator should purchase ferry f5. In that case, for 2019 the operator will provide 94500 $ less for the investment in the fleet (purchased and chartered-in) in comparison to 2018 because of the ferry f5 added to the existing fleet. Besides, the operator maximized the total profit. Most of the operating, voyage, maintaining and staying at the berth costs of an unallocated ferry would be lower if the operator's fleet consists of ferries with a smaller transport capacity. However, this will be the subject of some other investigations.

Table 4: Results of new scenario for 2019 [14]

	New profit ($)	Unused seats	Fleet structure
March	10261	336	f1, f3, f5, f11
April	35540	688	f1, f2, f3, f5, f11
May	87687.5	684	f1, f2, f3, f5, f11, f12
June	128372	755	f1, f2, f3, f4, f5, f11, f12
July	149834	732	f1, f2, f3, f4, f5, f11, f12
August	144841	828	f1, f2, f3, f4, f5, f11, f12
September	128670.5	1181	f1, f2, f3, f4, f5, f11, f12
October	79910	687	f1, f2, f3, f5, f11, f12
November	2256	332	f5, f11
Total	767372	6223	f1, f2, f3, f4, f5, f11, f12

As it can be seen, the total profit of a new scenario for 2019 is less than one in the case of having the fleet of ferries f1-f4. Therefore, a deeper analysis of a longer period should be taken into account. Also, for a detailed survey of the financial profitability, it is necessary to take into account the uncertainty in the level of transportation demands on an annual basis, mitigate the negative consequences and preparedness for an economic crisis, such as the one caused by the COVID-19 pandemic.

5. CONCLUSION

In this paper we presented the analysis of the ferry passenger transportation demands for a two-year time in the case of the Boka Kotorska Bay. The statistics indicate that the region was visited by more than 116 thousand tourists that sought the ferry transportation services on four different routes. We first provide the increase of operators' profit by employing the MILP model that suggested larger involvement of smaller ferries along Route 4. Next, we proposed a new scenario for creating a joint ferry company (operator) to deal with the possibility to purchase and/or charter-in additional ferries to achieve the increased income.

The results showed that the maximization of the total profit is a reality (increased from 1228036 $ to 1635385.5 $) covering the costs of a new ferry purchased and two ferries chartered-in. However, in the case of uncertain transportation demands and without the appropriate policy for economically sustainable ferry service development in a long term, the financial business of the operator may be treated as uncertain and record losses. To avoid it, special attention in the further investigation may be directed to the stochasticity of the transportation demands for the ferry services in the observed region.

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