Management of Groups of Passengers on Buses Considering the Restrictions of COVID-19

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Abstract: During the epidemiological emergency, the measures adopted by the governments to contain the spread of the virus have caused heavy changes in the passenger transportation sector. In this work, we address the problem of managing groups of passengers on buses considering COVID-19-related restrictions. We propose a linear integer programming model to represent mathematically the bus group assignment problem, whose main aim is to make the best seat-passenger assignment, in such a way that the social distancing constraints, imposed for containing the spread of COVID-19, are satisfied. The developed formulation, accordingly to the current Italian rules, considers not only the physical distancing among passengers, but also the possibility to allocate household groups close to one another. The proposed model is tested empirically considering a real case study of a bus company operating in Italy. The computational results reveal that our model could help the transportation company to effectively manage the capacity, improve customer service, and maintain the social distancing in order to prevent the risk of contagion, by maximizing the revenue.

1 INTRODUCTION

The ongoing global spread of COVID-19, started at the beginning of 2020, dramatically affects globalized societies and economies. All the governments prompted forceful measures for transmission containment, causing widespread social and economic disruptions. In this paper, we focus on the passengers transportation service, more specifically on buses sector, considering the pandemic restrictions related to the physical distancing. The report "Observatory on mobility trends during the COVID-19 health emergency", drawn up by the Mission Technical Structure for the strategic direction, infrastructure development and High Surveillance of the Italian Ministry of Infrastructure and Transport (MIT), shows that, in Italy, the journeys made through collective transportation services have undergone a more marked reduction compared to private/individual road transportation, reaching reductions even higher than 90% in the period March-April 2020 compared to the pre-COVID-19 period.

The second wave of spread of the virus and the consequent restrictive mobility policies have produced less marked effects on collective transportation than those observed during the first lockdown, with maximum reductions of 60%. In particular, high-speed rail journeys underwent a reduction of up to almost 100% in the period March-April 2020. This drastic peak was also recorded, in addition to the restrictive measures adopted, in the face of a reduction in the offered services by more than 95%. Movements on maritime services, instead, suffered a slightly different reduction in passenger demand compared to that observed for land services, with losses that amounted to around 90-100% in the period April-May 2020, and then began to grow, while still showing a significant reduction (about 20%) in passenger demand in July 2020. Finally, travel on air services has undergone a 99% reduction in both demand and supply, which has started in March 2020 and reached a minimum in the period April-May 2020, and then slightly has begun to grow. On March 20, 2020, the Italian shared regulatory protocol was adopted for the containment of the spread of COVID-19 in the transportation and logistics sector.

In the protocol, distance, protections and sanitation become imperative indications for the safe use of mobility services. The rules of distancing that regulate the "how to sit" on the various transportation vec-

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tors are rigid, just because they could represent a vehicle of contagion. Making collective passengers transportation safe and acceptable is the main goal of all the governments as well as of the transportation companies. Proposing flexible but effective solution for managing the available seats on a vehicle, considering physical distancing, guaranteeing the safety of the travellers and the containment of virus spread is crucial. However, an inadequate allocation of passengers may lead to an additional loss of revenues. Our main goal is to propose an effective strategy that, on the one hand, guarantees travellers safety, on the other one, maximizes the revenues as much as possible. In particular, we propose a linear integer programming formulation to represent the bus group assignment problem (BGAP, for short). The main aim is to manage the bus capacity (i.e., available seats), by maximizing the revenue and considering COVID-19 social distance restrictions. The rest of the paper is structured as follows: Section 2 describes the state-of-art on passenger transportation in the pandemic era and focuses on the limitations and rules imposed in Italy on the collective transportation. Section 3 presents a linear integer programming formulation for the BGAP under COVID-19 social distance in the case of bus passengers transportation service. Computational experiments are discussed in Section 4, while Section 5 summarizes the conclusions.

2 PASSENGER TRANSPORTATION IN THE PANDEMIC ERA

In this section, we firstly discuss briefly about passenger transportation, highlighting the importance of this sector. Secondly, we focus on the impacts of the Covid-19 pandemic on the collective passenger transportation, by analyzing several scientific contributions.

2.1 Passenger Transportation

Collective transportation provides everyone with personal mobility, giving each person the possibility to perform his/her daily activities, such as accessing to employment, schools, medical care, and community resources, as well as his/her occasional ones, such as reaching vacation spots. Collective transportation, public or private, may include buses, trains, underground rail systems, airplanes and also cars in the context of sharing services (Ferrero et al., 2018). Each type of transportation vector has its specific features, for example, an airplane is faster than a bus, however it is also more expensive. In general, among the key factors that influence customers choice between alternative transportation modes, there are the travel time, the cost and the convenience (Hancocka et al., 2021). Another important aspect that influences customers choice is the environmental sustainability. Recent surveys, as the one carried by the booking platform Omio (www.Omio.it), show that potential customers prefer to select transportation solutions, characterized by low emissions and small carbon footprint.

Collective mobility is central to the whole society, hence, offering efficient and effective services to customers is a critical aspect for all companies operating in this sector. To pursue this goal, it is important managing the available and limited resources avoiding any type of waste. Thus, finding methods that allow to optimize the capacity of the transportation vectors, trying to maximize the revenue from the sold tickets, is a very discussed topic. In fact, numerous authors have already addressed it in the past, see, e.g., (Lin et al., 2020; Wang et al., 2018; Ongprasert, 2006); however, it still represents a challenge for researchers, scholars and companies.

2.2 Consequences of the Pandemic on Transportation

In the last two years, the pandemic has contributed to increase the difficulties of managing capacity of transportation vectors. The new regulations, imposed to contain and stop the spread of infections on transportation vectors, are configured as additional constraints that must be taken into account when managing the capacity. Indeed, the rules of social distancing lead to a reduction of the bookable seats and, consequently, to a lower possibility of obtaining revenues deriving from the sales of tickets. Figure 1 shows the configuration that must be adopted by bus following the social distancing rules. The capacity limitation imposes that the seats adjacent to the one occupied by a passenger are forbidden, and therefore cannot be used to allocate other travelers.

For this reason, developing models that optimally manage the allocation of passengers on transportation vectors, maximizing sales and consequently the revenues, and respecting the distancing constraints is a current challenge for both the scientific research and the service providers operating in the passenger transportation sector. Although the reference context is new and constantly evolving, several authors have already addressed this topic under different perspectives and application fields. (Fischetti et al., 2021)

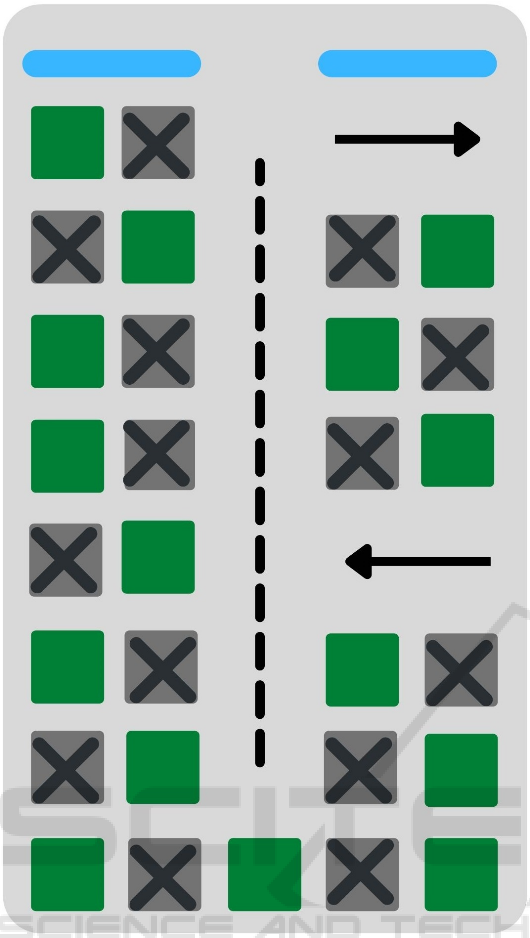

Figure 1: Layout and limitations of capacity on buses. The green squares represent the bookable seats; while crossed gray squares the forbidden seats, hence the not bookable ones.

study the problem of locating facilities in a given area, subject to social distancing constraints. The goal is to maximize the area utilization, as well as minimize the overall virus spread among facilities, following the social distancing rules. They analyze the similarities between this problem and that of locating wind turbines in an offshore area. In fact, similarly to people who can infect each other, also turbines located close to one another may to "infect" each other by casting wind shadows (the so-called "wake effect"), that cause production losses. The discovery of this parallelism allows the authors to apply mathematical optimization algorithms originally designed for wind farms, to produce optimized facility layouts, that minimize the overall risk of infection among customers. The results of the research show that in the structure of the safest layouts, the facilities are not equally distanced (as it is typically believed), but a policy, that significantly reduces the overall risk of contagion, tends to concentrate the facilities on the border of the available area. (Barry et al., 2021) consider a space allocation problem, that incorporates social distancing constraints, while optimising the number of available safe work-spaces, in an on-site working scenario. The solution approach is based on a bipartite graph of disconnected components over a graph of constraints. The obtained results are compared to a constrained random walk heuristic and a linear programming approach. A few contributions focused on the field of collective passengers transportation. (Salari R. et al., 2020) address the airplane passengers seat assignment problem, while ensuring social distancing among passengers. The authors propose a mixed integer integer programming model to assign passengers to seats on an airplane, such that two types of social distancing constraints are satisfied. The first type refers to passengers being seated far enough away from each other. The metric for this type of social distancing is how many passengers are seated so close to each other as to increase the risk of infection. The second one refers to the initial model to determine seat assignments, that maximize distance between seat assignments and the aisle. This distance influences the health risk involved in passengers and crew members walking down the aisle. Corresponding metrics for both passengers and crew members health risks are included in the objective function. The authors also provide an additional version of the initial model, in order to determine the seat assignments, that maximize the number of passengers boarding an airplane while practicing social distancing among passengers. The study of (Gkiotsalitis and De Weert, 2021) introduces a mixed-integer quadratic program that sets the optimal frequencies of public transportation lines and sub-lines, in order to conform with the pandemic-imposed capacity restrictions. The so called frequency setting model is tested on a network containing high-demand bus lines and it demonstrates that the revenue losses due to social distancing can be reduced when implementing short-turning service patterns. (Gongyu et al., 2021) redesign routes and bus schedules for University of Michigan's campus bus system, during the COVID-19 pandemic, with the aim to balance individuals safety and operational efficiency. In particular, they propose a hub-and-spoke design and utilize real data of student activities to identify hub locations and bus stops to be used in the new routes. (Moore et al., 2021) study the seat assignments with physical distancing in public transit considering a mixed-integer programming model defined to assign passengers to seats based on the specific configuration of the vehicle and desired physical distancing requirement. They also develop a

”household grouping heuristic” that allows household members to seats near to each other without respecting social distancing, and show that the proposed approach increases the capacity of the transit vehicles (e.g., airplanes, school buses, and trains) without increasing the risk of infection. The ongoing pandemic of COVID-19 and the constant change of rules to arrest the spread of the virus have been a high impact on transportation sector. Providing flexible models to manage the capacity during these sudden events is crucial for avoiding the service disruption. The majority of the reviewed works, focused on social distancing, hence on the reduction of the capacity of the vehicles. However, only one work, i.e., (Moore et al., 2021), considers the possibility to allocate household groups on adjacent seats. In our work we focus on this particular strategy, currently adopted in bus passenger transportation. For this type of transport, in fact, the current Italian rule establishes that the use of adjacent seats is limited exclusively to cohabiting passengers in the same housing unit, as well as between relatives and people who have stable interpersonal relationships. It is clear that this possibility could lead to a potential increase in the capacity of the vehicle (i.e., number of allocable seats), and consequently an increase in the number of sold tickets, hence to obtain additional revenues. Our work present some similarities with (Moore et al., 2021), in fact, they consider the allocation of groups of people on a bus. However, the main difference is that (Moore et al., 2021) consider a single-destination transportation service, in our work, instead, we consider more lines and a multi origin-destination scenario. In addition, (Moore et al., 2021) propose a heuristic approach to allocate the groups, while in our work we propose a mathematical model to handle the problem.

3 A LINEAR PROGRAMMING MODEL FOR GROUPS ASSIGNMENT PROBLEM UNDER COVID-19 RESTRICTIONS

We propose a mathematical model for managing different sized kin groups of passengers on the buses, respecting the social distancing limitations imposed by the Italian government rule reported in the previous section. The proposed model is an extension of the BSAP (Bus Seat Assignment Problem) formulation defined by (Guerriero et al., 2020). As in (Guerriero et al., 2020), we consider a passenger transportation company that offers a transportation service from a given set of origins to a given set of destinations. The company sells a set of products to several groups of customers on a given time horizon. Each product is an origin-destination (OD) transportation service performed by a bus. At each time of the planning horizon, the company has to decide how to manage the overall capacity in the most profitable way.

Let $E = \{e_1, \dots, e_n\}$ denote the set of n origins and $F = \{f_1, \dots, f_q\}$ the set of q destinations. A generic product is denoted as the pair $\{(e, f) : f > e, e \in E, f \in F\}$ and represents the OD transportation service from the bus station e to the bus station f. All the products are sorted in increasing order of the origin bus station and stored in the set (EF), that is $(EF) = (e_1, f_1), \dots, (e_1, f_q), (e_2, f_1), \dots, (e_n, f_q)$. The products offered by the company can be indexed as $p = (1, \dots, |(EF)|)$. We assume that the company performs the transportation service using a set of buses, each of them characterized by a given number of rows $i = 1, \dots m$, each row is composed by a certain number of seats denoted by l. In addition, we also assume that every bus has the same number of seats on each row. The number of seats per each row multiplied by the number of rows of the bus represents the seating capacity of the bus. The buses have t lines, $t = 1, \dots T$ and C^t is the capacity of line t that is the seating capacity of the bus, which runs on the line t. Each line t consists of a given number of stops denoted as $S_t + 1$ including the starting and the terminal bus stations and S_t legs between each two bus stations. All the products (i.e., OD transportation service) produced by each line t, $t = 1, \dots, T$ are stored in a sequence according to the incremental order of f and e, that is $(EF)^t = (1,2)^t, \dots, (1, S_t + 1)^t, (2,3), \dots, (S_t, S_t + 1)$. After numbering all the products in $(EF)^t$ from left to right, we can get the product sequence indexed by the serial number $p^t = (1, \dots, |(EF)^t|)$. Let $H^t = h^t_{sp^t}, s = 1, \dots, S^t, p^t = 1 \dots, |(EF)^t|$ denote a binary matrix, each element being equal to 1 if product p^t generated by the line t uses leg s and zero otherwise. Each column of matrix H^t contains all the information related to the legs involved in the OD transportation services provided by the line t. An example of matrix H^t for a line with $S^t = 5$ stops and 10 products is reported in Figure 2.

	Product									
Leg	(1,2)	(1,3)	(1,4)	(1,5)	(2,3)	(2,4)	(2,5)	(3,4)	(3,5)	(4,5)
(1,2)	1	1	1	1	0	0	0	0	0	0
(2,3)	0	1	1	1	1	1	1	0	0	0
(3,4)	0	0	1	1	0	1	1	1	1	0
(4,5)	0	0	0	1	0	0	1	0	1	1

Figure 2: Representation of of the matrix B, for a line with 5 stops and 10 products.

We assume that different lines can deliver the same OD transportation service from e to f, that is alternative products are available. Thus, in order to handle this specific situation, a binary parameter γ_p^t is introduced to denote the relationship between product p and line t. In particular, $\gamma_p^t = 1$, if the transportation service p can be delivered by the line t, that is $(e, f) \in (EF)^t$, and zero otherwise. Time is discrete, and at each time period of the booking horizon, the company has to decide on accepting/denying the request of a group of customers asking for a product p, that is an OD transportation service. The capacity of the system depends not only on the number of available seats for each row of a given line $t = 1, \dots, T$ but also by the size of the passenger group k with $k = 1, \dots, K$, that is assigned to the considered row. In fact, considering the restrictions in terms of social distancing between people that are not kin, we can allocate different types of groups on each row, with various configurations. Let's suppose that each row of the bus contains 4 individual seats. In this case, the possible assignment configurations for each row, depending of the group size, are the following:

- a kin group of 4 people,
- a kin group of 3 people,
- 2 groups of 2 people,
- 2 groups of 1 person,
- 1 kin group of 2 people and 1 single passenger.

Figure 3 represents an example of a layout configuration considering the limitation of capacity and the allocation of the groups. To model all the possible configurations, we introduce the matrix B, whose single element, denoted by b_{ij}^t, represents the number of seats, including those required to ensure the satisfaction of social distancing rule, used to allocate on the row i of the line t a group of k people, $j = (k-1)m + 1, \dots, km$. A representation of the matrix B, for the considered scenario, is given in Table 1, in which the matrix B is built by considering 2 lines $t = 1, 2$ and four group sizes $k = 1, 2, 3, 4$.

Table 1: Example of matrix B.

	k=1					k=2					k=3					k=4				
	m					m					m					m				
	2	0	0	...	0	2	0	0	...	0	4	0	0	...	0	4	0	0	...	0
t=1	0	2	0	...	0	0	2	0	...	0	0	4	0	...	0	0	4	0	...	0
	0	0	2	...	0	0	0	2	...	0	0	0	4	...	0	0	0	4	...	0
m	.					.					.					.				
	.					.					.					.				
	0	0	0	...	2	0	0	0	...	2	0	0	0	...	4	0	0	0	...	4
	2	0	0	...	0	2	0	0	...	0	4	0	0	...	0	4	0	0	...	0
t=2	0	2	0	...	0	0	2	0	...	0	0	4	0	...	0	0	4	0	...	0
	0	0	2	...	0	0	0	2	...	0	0	0	4	...	0	0	0	4	...	0
m	.					.					.					.				
	.					.					.					.				
	0	0	0	...	2	0	0	0	...	2	0	0	0	...	4	0	0	0	...	4

The main goal is to maximize the total revenue obtained from the accepted requests of a group of size k for the product p on the booking horizon. Moreover,

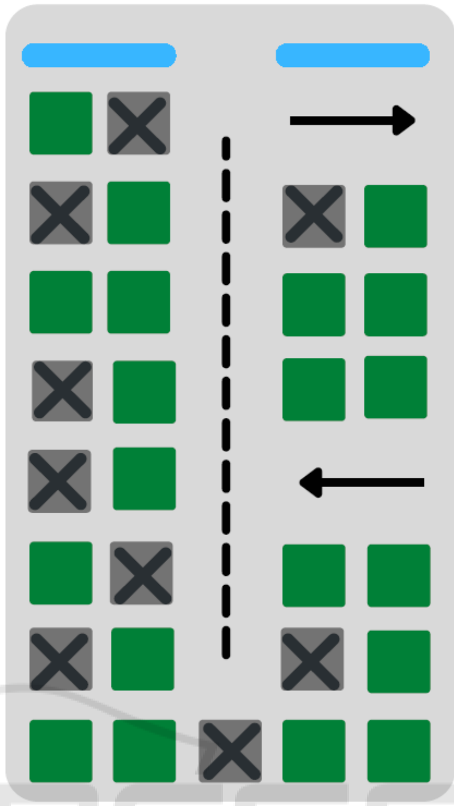

Figure 3: Example of a bus layout configuration considering the limitations of capacity and the allocation of kin's groups. The green squares represent the occupied seats; while crossed gray squares the forbidden seats. In particular, from the top (first line) to the bottom (octave line): a group of one person, two groups of one person, a group of four people, a group of three people, a group of one person, a group of one person and a group of two people, two groups of one person, two groups of two people.

it is assumed that booking requests made for groups with k greater than one cannot be partially accepted.

A summary of the parameters and the variables of the model is presented in what follows:

- R_p^k the revenue associated to the product p for a group of size k;
- d_p^k the number of request for a product p made by a group of size k;
- q the number of seats available on each row of the buses;
- $\gamma_p^t, p = 1, \dots, |(EF)|$, equal to 1 if the product p can be delivered by using the line t and zero otherwise;
- $h_{sp^t}^t, s = 1, \dots, S^t, p^t = 1 \dots, |(EF)^t|$ equal to 1 if the leg s is used in the product p^t and zero otherwise. $h_{sp^t}^t$ is an element of the matrix H introduced above;

- b_{ij}^t represents the number of seats used to allocate, on the row i of the line t, a group of k people, $j = (k-1)m+1,\ldots,km$. b_{ij}^t is an element of the matrix B introduced above;
- x_j^{pt} integer variables representing the number of satisfied requests for the product p by the line t.

The BGAP under COVID-19 social distancing rules is formulated as follows.

$$Max \sum_{p=1}^{|(EF)|} \sum_{t \in T} \sum_{j=(k-1)m+1,\ldots,km} \gamma_p^t x_j^{pt} \sum_{k \in K} R_p^k \quad (1)$$

$$\sum_{t=1}^{T} \sum_{j=(k-1)m+1,\ldots,km} \gamma_p^t x_j^{pt} \leq d_p^k \quad p = 1,\ldots,|(IJ)| \quad ,k = 1,\ldots,K \quad (2)$$

$$\sum_{p^t=1}^{|(EF)^t|} \sum_{j=1,\ldots,km} \sum_{p=1}^{|(EF)|} h_{sp^t}^t \gamma_p^t b_{ij}^t x_j^{pt} \leq q \quad t = 1,\ldots,T, s = 1,\ldots,S^t \quad (3)$$

$$i = 1,\ldots,m$$

$$x_j^{pt} \geq 0, \text{integer} \qquad p = 1,\ldots,|(IJ)|, t = 1,\ldots,T, j = 1,\ldots,km \quad (4)$$

The objective function 1 represents the total revenue obtainable. Equations 2 represent the demand constraints and state that the demand for a product p (transportation service) for a group of size k can be satisfied with all the products generated by all the lines t,$t = 1,\ldots,T$, that can deliver the considered transportation service. Equations 3 represent the capacity constraints and they assure both the respect of the social distance between different sized groups and the right allocation of capacity on the rows of the lines. Finally, constraints 4 define the variables domain.

Clearly, this model could be easily extended to any type of transportation vector, by opportunely changing the capacity constraints considering the specific features of the vector.

4 COMPUTATIONAL EXPERIMENTS

In this section, we describe the computational results collected to validate the proposed model. We used the software AIMMS 4.75.3.6 and the commercial solver Cplex 10.1, on an Intel Core i7-8565U CPU, 1.8 GHz, 8 GB of RAM.

The experimentation is divided into two main parts: the first one is aimed to assess the behaviour of the proposed model in terms of solution quality; the second one is devoted to investigate the performance of the model in terms of scalability. The instances used in the first part of the computational study are based on real data derived from www.simetbus.it: the web site of a bus company operating in the south of Italy, that is the Simet S.p.A.. Each instance is characterized by a certain number of inter-regional lines, with a capacity of 52 seats. In particular, the layout of the bus operating a certain line is composed of 13 rows, each of which is made by 4 seats. In addition, every line is composed of a given set of origin-destination products. A different fare is associated to each OD product for a group of size k. We consider 4 possible types of groups. In particular, a group can be composed from a minimum of one person (a single passenger) to a maximum of 4 people. In Table 2 we reported the three lines considered for our tests, taken from the Simet S.p.A. website.

Table 2: Characteristics of Instances: Lines and OD products.

Line1		Line2		Line3	
origin	destination	origin	destination	origin	destination
1	6	1	5	1	6
2	6	2	5	2	6
3	6	3	5	3	6
4	6	4	5	4	6
		1	6	1	7
		2	6	2	7
		3	6	3	7
		4	6	4	7
		5	6	6	7

Looking at Table 2, the three lines and 7 cities (origin or destination) numbered in ascending order are reported on the columns. Each line is characterized by a set of OD products, depicted on each row of each line. In particular, the Line1 has 4 OD products with different origins but the same destination (i.e., 6). Line 2 and Line 3 are composed of 9 OD products. In addition, we may notice that the lines have in common some rides. For example, the product 1-6 is present in all the lines; hence, departing from the origin 1, it is possible to reach the destination 6 by using all the three lines. Regarding the legs, we may say that the Line 1 has 4 legs, Line 2 is composed of 5 legs, while Line 3 of 5 legs. The demand value for each ride is randomly estimated. In the computational study we compare the results obtained by allocating the customers using the proposed BGAP, with two other seat allocation policies. In particular, in the first policy we consider a FIFO strategy in which the demand of groups is allocated following the arrival order, respecting social distance but without any type of optimization. The second policy, named "NO GROUP", consists in a strategy that does not consider the possibility to allocate two or more relatives close to one another. Table 3 summarizes the results. In particular, the second, third and fourth columns report the three strategies used to allocate passengers (i.e., solving the BGAP model, the FIFO strategy and the NO GROUP strategy, respectively). On the rows, for each strategy, we report the total revenues, expressed in euro, the available seats, the occupied seats, the interdicted seats (i.e., the number of seats that cannot be occupied for maintaining the social distancing), and the unoccupied seats (i.e., seats that remain empty because they can not satisfy the demand that arrives for certain OD products).

Table 3: Computational results: BGAP vs FIFO vs NO GROUP.

	BGAP	FIFO	NO GROUP
Total Revenue	2.036,00	1.707,00	1.115,00
Available seats	156	156	156
Occupied seats	139	117	78
Interdicted seats	35	21	78
Unoccupied seats	0	18	0

The values, reported in Table 3, clearly show that the highest value of revenue is obtained by applying the BGAP model. Thus, the BGAP strategy is the most effective compared with the FIFO and the NO GROUP approaches. In particular, the BGAP model leads to an increase in the revenue, over the other two strategies, of about the 19.3% and 82.6%, respectively. In addition, we can notice that BGAP ensures the highest number of occupied seats and the lowest number of interdicted seats compared with FIFO and NO GROUP. Using the BGAP model to allocate the passengers, the value of the occupied seats is 18.8% and 78.2% higher than the FIFO and NO GROUP approach, respectively. Thus the BGAP model allows an effective management of the capacity. It it worth noting that the sum of the values associated with "Occupied seats", "Interdicted seats" and "Unoccupied seats" do not always correspond to the value of "Available seats".

This can be easily explained by taking into account that we have considered lines, characterized by several stops, in correspondence of which passengers can get on and off the vehicle. This means that some seats could be interdicted and/or occupied more than one time and, hence, counted more than once as occupied or interdicted seats. To better clarify this issue, let's consider the stop 5 of the line 2 defined in the Table 2. At this stop all passengers whose destination is 5 get off, while those who must go from 5 to 6 get on. Consequently, the seats occupied by the passengers who get off at stop 5 become available and thus they can be occupied again by passengers who get on the bus at stop 5 to reach destination 6. Thus, the same seat could be occupied by a passenger over a leg and interdicted over another leg according to the size of groups allocated on the row in which the seat is located. In fact, as we can see in the second column of the Table 3, the sum of "Occupied seats" and "Interdicted seats" is higher than the value associated to the "Available seats". Moreover, solving the model does not require high computational time, about 0.02 second on average, hence it is also efficient.

In the second part of the computational study, aimed at evaluating the scalability of the proposed model, we consider a set of randomly generated instances of increasing size.

Table 4 provides, for each test problem, the number of lines, the number of legs and the number of products. For example, instance T_10_1 refers to a bus network characterized by 10 lines, each line has 5 legs, and 5 available OD products. For each instance, demand and revenue values are randomly generated in the interval [0;10] and [5;300], respectively.

Table 5 summarizes the computational results obtained by solving the BGAP model. In particular, for each instance, it provides the objective function value (column "Revenue") and the execution time (column "Time") in seconds.

Table 4: Test Problems.

Test	Lines	Legs	Products
T_10_1	10	5	5
T_10_2	10	5	10
T_10_3	10	10	10
T_10_4	10	20	20
T_10_5	10	50	50
T_10_6	10	50	100
T_10_7	10	300	300
T_10_8	10	300	600
T_20_1	20	10	10
T_20_2	20	10	20
T_20_3	20	10	40
T_20_4	20	50	50
T_20_5	20	50	100
T_20_6	20	50	200
T_20_7	20	300	300
T_20_8	20	300	600
T_20_9	20	300	1200
T_50_1	50	50	50
T_50_2	50	50	100
T_50_3	50	300	300
T_50_4	50	300	600
T_50_5	50	500	500
T_50_6	50	500	1000

Looking at Table 5, it is easy to notice that the revenues increase with the increasing of instances size. This is an expected behaviour, since the higher the demand and the capacity, the higher the revenue.

In order to analyze the dependency between the computational overhead, required to solve the BGAP model and the instances size, in Figures 4 – 8 we depict the execution time as a function of instances characteristics (i.e., number of lines, legs and products).

Table 5: Computational Results on randomly generated instances.

Test	Revenue	Time
T_10_1	13022	0.02
T_10_2	33433	0.02
T_10_3	31190	0.03
T_10_4	44375	0.03
T_10_5	57632	0.08
T_10_6	61593	0.33
T_10_7	63941	3.86
T_10_8	65324	8.91
T_20_1	33806	0.03
T_20_2	59243	0.08
T_20_3	93001	0.08
T_20_4	101655	0.42
T_20_5	111050	0.77
T_20_6	124264	0.77
T_20_7	126783	9.48
T_20_8	128991	18.2
T_20_9	130580	36.08
T_50_1	146102	0.44
T_50_2	236471	0.78
T_50_3	413181	25.45
T_50_4	664210	54.91
T_50_5	586031	96.19
T_50_6	965359	202.63

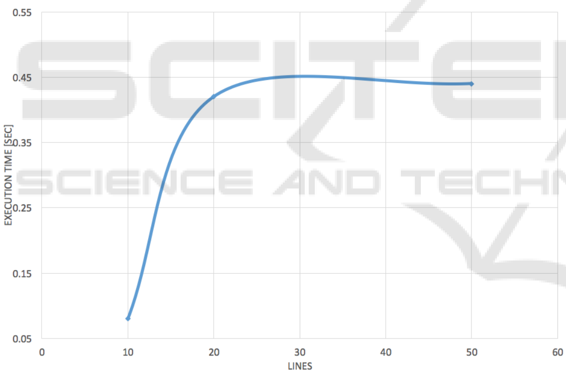

Figure 4: Execution time as a function of the number of lines, with fixed number of products and legs (50 legs, 50 products).

Focusing on the results depicted in Figures 4 - 7 we can notice that the higher the number of lines, the higher the execution time. In particular, considering Figures 4 and 5, which refer to the results for instances with 50 legs and 50 products, and 50 legs and 100 products, respectively, it is evident that the execution time sharply raises when the number of lines increases from 10 to 20, then, after 20 lines, it continues to slightly raise with respect to the number of lines. Looking at Figures 6 and 7, which depict the results obtained for instances with 300 legs and 300 products, and with 300 legs and 600 products, respectively, it is easy to observe that the execution time sharply increases with the increasing number of

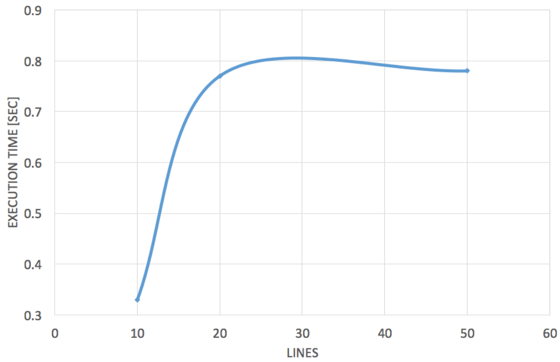

Figure 5: Execution time as a function of the number of lines, with fixed number of products and legs (50 legs, 100 products).

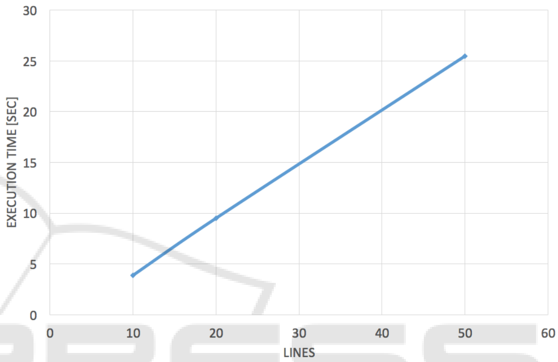

Figure 6: Execution time as a function of the number of lines, with fixed number of products and legs (300 legs, 300 products).

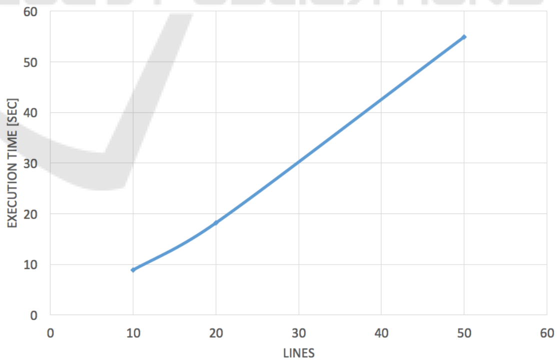

Figure 7: Execution time as a function of the number of lines, with fixed number of products and legs (300 legs, 600 products).

lines. Thus, looking at Figure 8, which summarizes the overall results obtained on all the classes of instances, we can state that the feature, which influence the most the computational overhead is the number of legs, and consequently the number of products, while the number of lines has not a relevant impact on the execution time. The plots reported in the Figure 9, which depict the execution time as a function of the

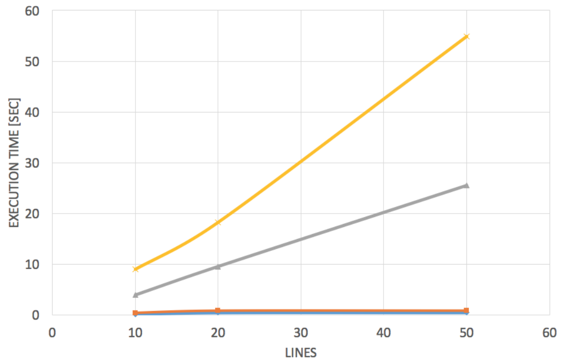

Figure 8: Execution time as a function of the number of lines, with fixed number of products and legs: Orange line: instances with 50 legs, and 50 products; Blue line: instances with 50 legs, and 100 products; Grey line: instances with 300 legs, and 300 products; Yellow line: instances with 300 legs, and 600 products.

number of legs, fixing the number of lines, confirm the strictly dependence of the execution time on the numbers of legs and products.

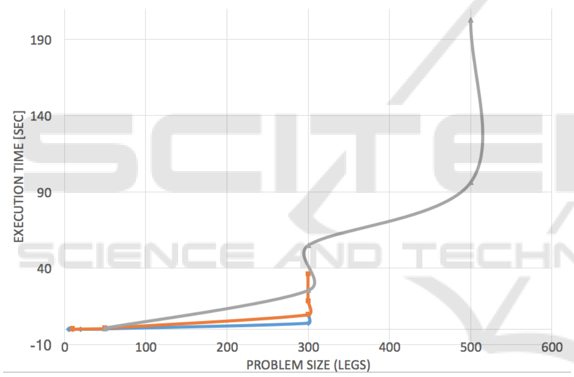

Figure 9: Execution time as a function of the number of legs, with fixed number of lines. Grey line: instances with 50 lines, Orange line: instances with 20 lines, Blue line: instances with 50 lines.

Finally, looking at Figure 10 that represents the trend of the average execution time with respect to the increase of the problem size, we can notice that, the computational time increases with the increasing problem size, in terms of number of lines, number of legs, and number of products considered, on average.

It is important to highlight that overall the resolution of the BGAP model has short execution times, i.e., in the order of minutes, even for large instances (e.g., T_50_6). Thus, the BGAP model is efficient for finding optimal solutions also considering more realistic sized instances. We may conclude that the use of the BGAP model allows to efficiently and effectively manage the seats assignment and groups of passengers, by optimizing the seats allocation, respecting the rules of social distancing imposed to reduce the diffusion of the COVID-19 virus.

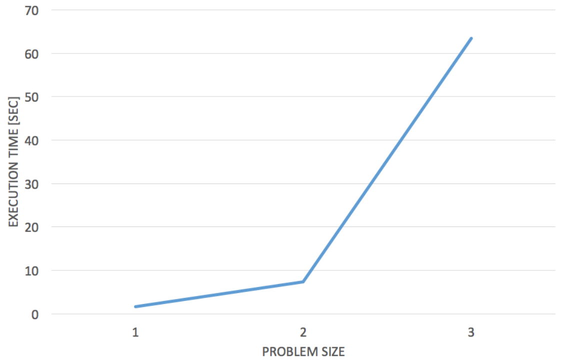

Figure 10: Trend of the average execution time with respect to the increasing problem size.

5 CONCLUSIONS

In this paper we have considered the problem of allocating groups of passengers on the buses during the pandemic time. The main goals are: creating safe configurations by respecting social distancing, optimally exploiting the capacity of vehicles and maximizing the revenue deriving by the sale of travel tickets. In particular, we considered the possibility to allocate groups of relatives close to one other, following the Italian rules currently adopted on the buses. However, it is worth noting that this model could be easily extended to any transportation vector type, by modifying the capacity constraints, considering the specific features of the transportation vector. In the computational experiments, we made a comparison between the results obtained with and without the application of the proposed model. The results highlighted that our model provides more effective solutions than the common FIFO or NO GROUP strategies. In addition, we investigate the scalability of the model, by considering a set of randomly generated instances of increasing size. The results highlighted that the computational times increase with the increasing number of lines. However, solving the model requires a reasonable amount of time. Thus, we may conclude that our model could efficiently help the bus transport company to optimize the managing of resource-constrained buses and, at the same time, maximizing the revenue, considering the rules of social distancing. Hence, our model represents a valid support tool for managing the passengers seats allocation by minimizing the risk of contagion.

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