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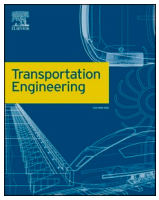

Managerial decisions to recover from Covid-19 disruption: A multi-objective optimization approach applied to public transport operators

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ABSTRACT

The resilience of transport systems, facing natural or man-made disruptions, has been widely discussed in literature in terms of recovery capabilities concerning infrastructures, suggesting solutions to provide users an acceptable level of service along the interrupted network. However, in the context of the Covid-19 outbreak, the disruption has stressed the resilience of transport systems not on the supply side but rather at organizational level for transport service providers. Indeed, the sudden and drastic decrease in users due to the restrictions imposed by governments to limit the pandemic spread has implicated severe economic consequences in the running of transport companies. In this paper, attention has been focused on the public transport sector to analyse the effects of different initiatives, which companies could undertake in response to the demand shock caused by the Covid-19 emergency. Notably, an optimization procedure has been developed with the aim of determining feasible Pareto-front solutions, which correspond to trade-off conditions for the concurrent maximization of the company profit and the minimization of outsourcing services. The time span necessary to implement the examined recovery measures has been considered together with the limitation to appropriate threshold values for the main cost and income items influencing the company operations management. The proposed approach has been applied to the case study of an Italian public transport company to appraise different post-Covid-19 resilience strategies.

1. Introduction

The crucial role of public transport within the transport system is widely acknowledged by practitioners and researchers, since it represents one of the most significant modes of mobility enabling to serve many people in a sustainable way [1]. Therefore, especially in major cities, the offer of high-quality public transport systems is essential to meet transport demand and it entails different operational requirements on those systems, notably with respect to reliability and efficiency [2]. These latter key features largely depend on the capabilities of public transport companies to provide quality services, which in turn derive from both technical and managerial aspects. Given the relevance of public transport for communities, its functioning requirements should be guaranteed even in disruptive situations, which call transport operators upon to the implementation of appropriate strategies to cope with the consequences of non-ordinary detrimental circumstances. The ability of a system to return to normal conditions after natural or man-made disasters is captured by the wide notion of resilience, whose definition can be declined according to the different perspectives characterizing the relative application field [3,4]. As regard the transport sector, in [5] the authors performed a systematic review of studies concerning transport resilience, from which its significance results to have overlaps with further recurrent concepts like reliability, robustness, vulnerability, and survivability. Indeed, the literature analysis carried out in [5] suggests that the first two terms, along with redundancy and recoverability, constitute the attributes, which mainly contribute to the resilience performance of a transport system.

The scope of existing investigations on resilience in the transport context largely concerns transport supply, i.e., the functional resilience of critical transport infrastructures. For such infrastructures, which are usually compromised by natural disasters, technical improvements to reduce the system vulnerability and the negative effects of disruptive events are proposed [6]. However, the opportunity of extending the notion of transport resilience to explicitly include also sociotechnical

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factors has recently emerged thanks to evidence revealing the influence of some resilience aspects of the ecological, social and economic domains on the transport field [6,7]. Suggested by the analogy with those sectors, the embracement of a wider range of attributes to define the resilience of transport systems highlights the meaningful role of the adaptability to unstable environments, which enables systems to persist. In this regard, a further, though more limited, research stream concentrates on transport demand and examines the persistence of customers in using a specific transport infrastructure following any kind of system disturbance, like, for example, terrorist attacks [8]. In addition to methodologies dealing with issues related to supply shocks or notable demand fluctuations, the resilience of public transport systems has been discussed at organizational level, considering the management of public transport companies and, thus, analysing "the capacity of an organization to survive, adapt and grow in the face of turbulent change" [9]. With the aim of achieving such ability, public transport operators are encouraged to adopt a comprehensive resilience approach leading to a balanced matching between enterprise's capabilities and its potential vulnerabilities, in the view of performance improvements. As a matter of fact, managing resilience definitely helps organizations to shorten both problem-identification and problem-resolution time, enhancing their responsiveness to disruptions and, consequently, speeding up their recovery [9]. On a more general scale, resilience acknowledges the potential occurrence of disruptions and addresses the resolution of concerns on a longer time horizon, which ensures the avoidance of short-term profitability and apparent efficiency. To this end, particularly in complex and interconnected systems, decision makers are recommended to transit towards resilience-by-design systems in contrast to strategies based on the prevention of threats or at least on the mitigation of their consequences [10].

The outbreak of Covid-19 is one of the biggest unpredictable disturbances that affected public transport systems worldwide in the recent past, causing a drastic reduction of services and heavily hindering their use due to the restrictions implemented by governments to limit the pandemic spread [11–13]. Together with the practical detrimental impacts in the immediate aftermath, such unexpected shock entailed psychological side effects on users which led to a decrease in their perception of public transport safety [14]. The fear of using public transport services has altered the habits of customers, who shifted to alternative transport modes, namely private cars or more active ones, like walking, cycling and micromobility solutions, especially during peak infections periods [15–18]. For public transport companies the Covid-19 outbreak implicated a quite significant rearrangement of operations, which mainly consisted in a modified deployment of resources in order to comply with the requirements of social distancing and sanification procedures. The former imposition has undoubtly represented the primary barrier in carrying out public transport services because of the reduction in vehicle capacity. Although public transport companies accordingly adapted their supply to provide users with the essential services, they ended up encountering serious financial issues that could possibly jeopardise their survivability. To avoid the failure risk, in these unconventional circumstances public transport organizations have been challenged to develop and realize effective countermeasures in the effort to restore the pre-disruption operational activity. In line with this purpose, the assessment of managerial decisions on the overall enterprise's performance proves to be extremely important since it permits to capture the relation between the two [19].

Even if restrictions have been lifted almost completely in the majority of countries all over the world, uncertainty on the pandemic evolution strongly exists because of the potential occurrence of future waves caused by the rise of new virus variants. Such instability concering global healthcare conditions along with now consolidated alternative travel patterns, contribute to the fact that public transport ridership may not have resumed to the pre-Covid 19 rate yet and, thus, make the need of undertaking resilience-oriented interventions still pressing. These issues motivated the study reported in this paper, which consists in the development of a multi-objective optimization approach to evaluate the most efficient arrangement of managerial initiatives to ensure the financial survivability of a public transport company. In line with policy recommendations suggested in literature, e.g., in [20], this paper drives an advancement in existing knowledge proposing an innovative methodology which aims at the balanced combination of public transport operations outsourcing with a variation in the service offer and fares as a strategy to cope with the revenues losses due to the significant decrease in the number of bus users. The realization of such interventions has been analysed both in terms of implementation time and in light of the operational limitations needed to respect social distancing, without overlooking regulatory constraints on service provision.

The structure of the manuscript considers in the second section a literature review regarding the impacts of the Covid-19 pandemic on the transport field, especially in terms of changes in users' travel behavior, and on strategies to ensure the financial survivability of transport companies in the disruption aftermath. The third section explains the proposed methodology highlighting the assumptions made within the appraisal process, while the fourth section describes the application of the adopted approach to the case study of an Italian bus service provider. The outcomes of the optimization procedure are explained and discussed, respectively, in the fifth and sixth section, along with their graphical visualization. Finally, conclusions on the effectiveness of applying resilient lines of action in public transport organizations are drawn, suggesting future advancements to refine the developed technique.

2. Literature review

Since the pandemic outbreak, several studies have been developed to analyse the effect of Covid-19 on the transport field, from which it turned out that this latter was the sector most affected by restrictions on economic activities and social contacts [21]. Referring to public transport, investigations have dealt with such issue according to a variety of perspectives, each of them constituting a distinct research stream but, at the same time, interconnected with the other ones. Indeed, just to name a few, available scientific contributions range from analyses of changes in users' travel behavior and related influential factors, to explanations of policy measures put in practice by governments and transport operators to ensure the provision of adequate transport services and the financial sustainability of companies. Modified users' mobility attitude and choices during the pandemic have been discussed especially in terms of mode preferences, revealing a significant and diffused modal shift from public transport towards private vehicles and to solutions like walking or cycling. A comprehensive study marking such variation is described in [22], which summarizes the results of a world-wide survey administrated to several acknowledged transport experts. Authors of [22] estimate that the geographical extension of the survey and the eterogeneity of the interviewed panel assist the validity of the illustrated figures (e.g., a 64,8% shift to cars), making them a representative outcome of the diversion registered in the public transport sector. Similar evidence concerning users' avoidance of public transport is reported in [23], which illustrates the insights coming from a cross-country study on individual travel patterns for all transport modes, before and during the implementation of pandemic-induced restrictions. Notably, based on users's perception of the potential virus spread, airplanes and buses have proved to be the most dangerous transport modes among the examined ones. Besides, referring to further scientific studies, the motivations for modal shift have been contextually investigated in order to capture the main factors contributing to such trend. The literature review performed about these latter revealed that the most influential factors regard both socio-economic and transport-related aspects, respectively in terms of gender, income, education, and employment status, and of vehicle ownership, trip frequency, travel distance, and safety (e.g., [14,24–26]).

Since the major focus of this paper concerns the resilience of public transport companies, the literature review has been performed paying attention to studies falling into that line of research, although without overlooking the significant outcomes obtained in the abovementioned investigations. In fact, such results constitute interesting and useful suggestions about users's behaviour trends on which managerial decisions partially depend, in line with the overall principle of balancing demand needs and transport services supply. The survey on state-of-art contributions has been concentrated on the few articles describing operational and policy measures able to favour operators' survivability thanks to the following strategies: on one side, the provision of flexible collective services and, on the other side, service contracting. Reason for this is that these two aspects recall to the features of the methodology proposed in this paper to foster the resilience of public transport companies, and they differ from the several variations made in supply provision at tactical level by many transport companies when determining the allocation of resources, like changes in service frequencies, timetable and line planning, stopping patterns and service span [13]. As far as the first kind of strategy is concerned - provision of flexible collective services-, in [27] the authors describe the development of a demand responsive transport (DRT) service which was implemented in Britain to face the pandemic shock and, on top of that, to cope with the already declining bus use in the country. The introduction of such service was intended as a post pandemic recovery measure able not only to achieve cost efficiency, but also to offer an improved service for a large user basin. As a matter of fact, the integration of the DRT service in support to the conventional commercial bus operations, and not in competion with them, allowed to supply users with a more inclusive and sustainable transport system while ensuring the financial viability of the provider.

Regarding policy measures implemented to mitigate the impact of Covid-19 on the public transport sector, governments have sustained operators with various financial schemes in the form of either stimulus/relief funding packages [28], leading even to free-fare public transport offering [29], or direct involvement in the service provision model, like in case of transport companies adopting service contracting (*SC*). [30] reports how this second alternative represented a successful innovation for Philipinnes based on three key indicators, i.e., the social amelioration, the transport supply increase and the improvement of the transport system performance. By means of mixed methods and several data sources, the authors of [30] recorded that the positive effects of the implemented SC program were accomplished mainly thanks to a guaranteed income for operators and led to an even broader advancement of the public transport system. In face of the benefits reached through the actualization of social contracting, the authors highlight the crucial role of a proper design of contracts, to determine a sound balance between state supervision and private service provision while contrasting deregulation in the transport field. The design of contracts is considered a key issue even in [31], in which, with reference to Brazilian context, the authors suggest taking advantage of the inherent incompleteness of such agreements, paired with the unpredictable occurrence of the pandemic, to motivate possible amendments to the economic and financial terms regulating the involvement of the two parts. To this end, practical recommendations for a smooth and effective implementation of contract modifications are given, stressing the relevance of ensuring the transparency of the decision-making process. Suggestions are provided with respect to both the administrative and the operational level, covering a variety of scenarios characterized by different pandemic-related circumstances.

As anticipated, in line with the goal of the present paper, the reported scientific studies concentrate on the effect of strategies for the financial recovery of transport companies, given the ability of public transport services of revitalizing further business activities. Nevertheless, this paper offers a twofold added value because of the following reasons:

– a combination of operational and regulatory factors has been considered to improve the resilience of the service provider, encompassing untraditional actions which aim to strive for a re-establishment of users' confidence in public transport;
– a multi-objective optimization procedure has been performed taking into account also time-related aspects of the implementation process and of the expected financial impact of suggested solutions.

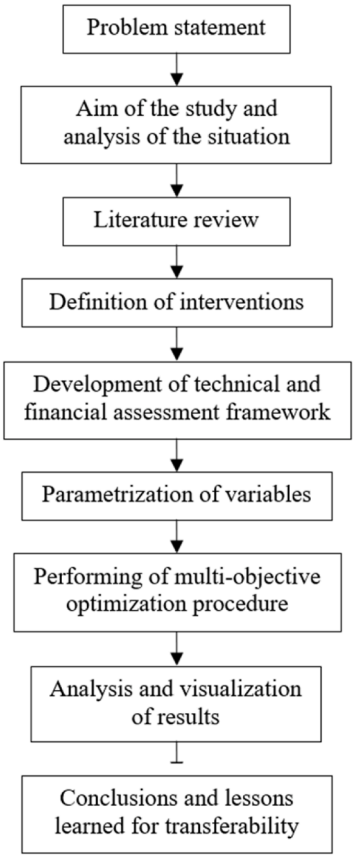

Fig. 1. Data flow chart of the proposed methodology.

3. Methods

The potential of organizational resilience strategies in increasing the probability of companies' survival is captured in the holistic management process called "Business Continuity Management" (BCM), which guides organizations in the identification of possible threats and of their consequences on business operations, providing a framework to build resilient actions [32]. One of the goals of business continuity planning consists in the appraisal of the financial impacts of potential disturbances on business, which is usually referred to as "Business Impact Analysis" (BIA) [33]. As reported in [34], carrying out such analysis allows to determine an organization's key products or services, and its critical functions, in order to obtain the BC-related indices expressing the maximum tolerable period of disruption and the minimum business continuity objective. In line with this approach, in this paper a multi-objective optimization procedure has been developed to define a set of optimal solutions for the financial recovery of a public transport operator, with the aim of formulating recommendations for its survival after Covid-19 disruption. The configurations of the identified optimal solutions derive from trade-offs among selected variables and provide some insights on various scenarios of intervention, which take into account the temporal dimension.

At methodological level, the steps indicated in the data flow chart of Fig. 1 have been implemented. First of all, the problem statement has been derived from the acknowledge of the financial consequences of pandemic-related mobility restrictions on public transport operators,

Fig. 2. Schematic representation of the public transport network in Trieste.

leading to the definition of the abovementioned aim of the study. This latter has been followed, on one side, by the analysis of the operational status quo and, on the other side, by the performing of a literature review concerning the impact of Covid-19 on the transport field and possible resilient strategies for the operators' financial survivability. Given the lack of existing comprehensive solutions, further interventions have been identified bearing in mind the peculiar features of the considered case study, and a technical and financial assessment framework has been developed to prove their effectiveness. The parametrization of the framework input variables was then necessary to perform the multi-objective optimization procedure, whose results were analysed and visualized in different graphical forms. Finally, some conclusions on the outcomes obtained by the applied methodology have been drawn, also in the light of their transferability to other contexts.

Regarding the definition of interventions, with reference to the criteria included in the classification of possible managerial activities proposed by [19], attention has been focused on the network-related category which encompasses the resorting to additional modes to provide users with public transport services. Indeed, with the purpose of reducing its financial expenditures, the public transport company is presumed to partially outsource its transport offer substituting the subcontracted supply through either similar bus services or introducing Car-Hire-With-Driver (CHWD) services. As claimed in [35], the need of mitigating the effects of pandemics like the Covid-19 on work and employment trends represents one of the motivations that leads organizations in general to resort to outsourcing, in the effort to ensure their survivability. According to the principles of the Transaction Cost Economics theory, outsourcing is convenient when transaction costs of contracting out do not exceed production cost advantages: in that case, companies manage to reduce their overheads and in-house employees are able to focus more efficiently on core competencies and businesses. In line with that, using small capacity vehicles to perform the CHWD services is intended to make the public transport offer more appealing with respect to users' perception of its safety, while enabling higher revenues as compared to traditional buses and lower operational costs for the transport company.

Then, a simplified technical and financial assessment framework has been developed with the aim of reflecting the effects of managerial decisions on the enterprise cash flow and, thus, estimating its profit. Furthermore, the following constant parameters have been set according to the real life values in the considered case study: the cost per km for the different considered services (4,4 Euro/km for traditional buses, 2,5 Euro/km for subcontracting buses and 1,2 Euro/km for CHWD services), the bus ticket fare (1,25 Euro/trip), the annual travelled distance (13,2

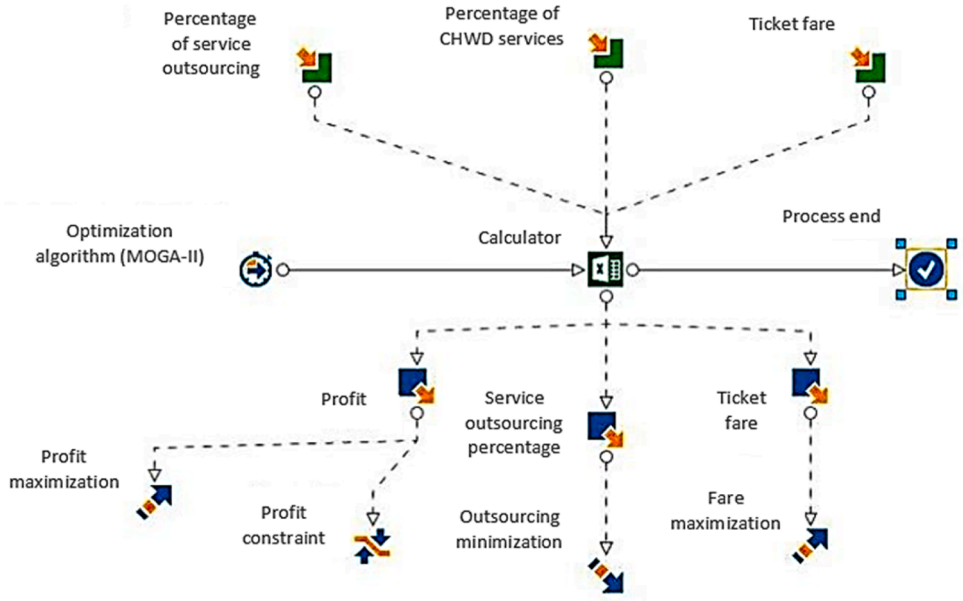

Fig. 3. Workflow for the optimization procedure.

Mkm/year), the number of buses composing the company fleet and of employees, and the yearly average of transferred passengers (70 M persons). Some assumptions have been made with respect to both the level of occupancy of vehicles deployed for the diverse kinds of transport solutions (based on passengers counting), which has been reduced by 50% to consider the effect of social distancing, and to the different timing needed to actually implement and operationalize them. In this regard, as underlined in [19], the specification of the length and the structure of the time lag elapsing between the undertaking of managerial decisions and their repercussion on the enterprise's economic performance definitely influence the assessment of the magnitude of those impacts. Subsequently, annual costs and revenues per km have been calculated for each transport alternative, lowering their potential capacity and hypothesizing a different gradual introduction of outsourced services throughout the months over a year time span. Analogous estimations have been performed to determine the annual costs and revenues against the total distance travelled in one year based on a varying monthly amount of kms for the subcontracted services, whose entity depends from their progressive implementation stage. Lastly, the multi-objective optimization procedure has been performed by means of a Multi Design Optimization (MDO) framework, which optimizes engineering design processes through innovative algorithms and the integration with leading simulation tools. The MDO framework enables the definition of the details of engineering design processes through an intuitive workflow, which formulates all the logical steps composing the processes and defines the input and the output variables. The MDO framework workflow allows the integration between external "simulation" tools as a Black Box, which contains the procedures that should be used to compute the values of the output variables according to the input variables of the engineering design process. For instance, the Black Box can be a calculator, a script, a specific external procedure or an external tool, such as Computer-Aided Engineering (CAE), Computer-Aided Design (CAD) and Finite Element Methods (FEM) tools. The Black Box is defined in the MDO framework workflow by means of specific nodes. The MDO framework contains, on one hand, iterative optimization algorithms, including genetic algorithms, for both single and multi-objective problems and, on the other hand, Design of Experiments (DOE) algorithms, which are usually used to define the initial population for optimization algorithms.

In summary, given a set of Input Variables (in this specific case, some possible managerial decisions), the "simulation" engine is composed by a model that can reproduce the corresponding Output Variables (which can be goals or constraints). The MDO approach closes the loop towards optimal and feasible solutions. Such kind of optimization methodology has been already used for another application in the transport sector, as described in [36].

4. Case study

Trieste is a middle-sized European city, located in the Northern East of Italy on the Adriatic Sea, at the border with Slovenia. Thanks to its more than 200.000 inhabitants, it is among the top 15 Italian cities in terms of population. Due to the peculiar configuration of its landscape (presence of hills), the modal share towards non-motorized transport modes is quite low and public transport plays a key role in urban mobility, not only for commuters. Fig. 2 displays a schematic representation of the public transport network of the city of Trieste indicating all the existing routes and stops (green dots): it is composed by 56 lines of traditional bus services, one tram line and an experimental on demand bus service has been proposed in recent months. The service is quite well distributed both in space and time, and it is characterized by a high-quality level. The total amount of km/year is around 13 million, with a fleet of 273 busses and 6 trams. The service is operated by a private-public company of almost 800 employees based on a Service contract with the public authority, which defines goals and constraints, and fixes the revenues scheme and thresholds. An important operational constraint concerns the minimum service level that the company must guarantee to users.

Before lockdown due to Covid-19, Trieste was the fourth city in Italy in terms of the ratio between transit passengers and inhabitants, after Rome and Milan (i.e., the largest cities in Italy with metro-rail services) and Venice (where no other transport mode than pedestrian transit is possible and the presence of tourists is significant). During and immediately after lockdown, the number of trips has drastically reduced owing to a series of different reasons. Indeed, a large portion of citizens does not commute any more to their workplace thanks to the so called "smart working"; schools were closed so no transfers of students are recorded; the University offers on-line services (before the Covid-19 outbreak, the University population equalled almost to 10% of the city inhabitants); and, lastly, people prefer other transport modes (mainly private cars and scooters) due to a lack in their security perception when using public transport. Therefore, the revenues of the local public

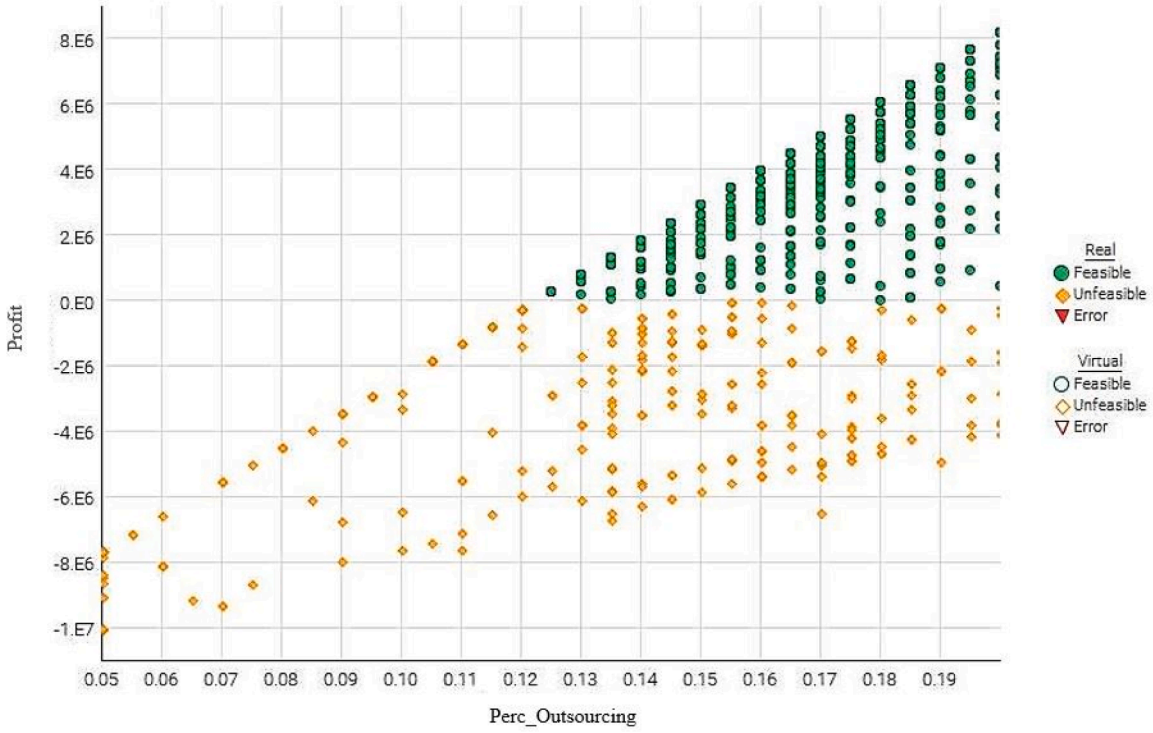

Fig. 4. Relationship between outsourcing percentage and profit.

transport company have strongly reduced, also because during lockdown nearly 70% of services had to be guaranteed by contract. The additional constraint given by the imposition of a minimum distance among people has led to an increase in the transfer services to be performed and, consequently, to an increase in costs, evidencing the need of adopting alternative managerial solutions. These latter may include actions on operations, costs, and fares but, in any case, they must be compliant with the service agreement at least in terms of service level.

According to the proposed methodology, the following input variables have been selected as the principal characteristics of the considered managerial solution, which consists in subcontarcting part of the company's service supply: the global percentage of services to be outsourced, the relative share of CHWD services, and the single-trip ticket fare to be imposed to users for the deployment of CHWD services. Due to the great value of total kms/day to be offered, a maximum amount of outsourced services has been fixed in order to consider a limited

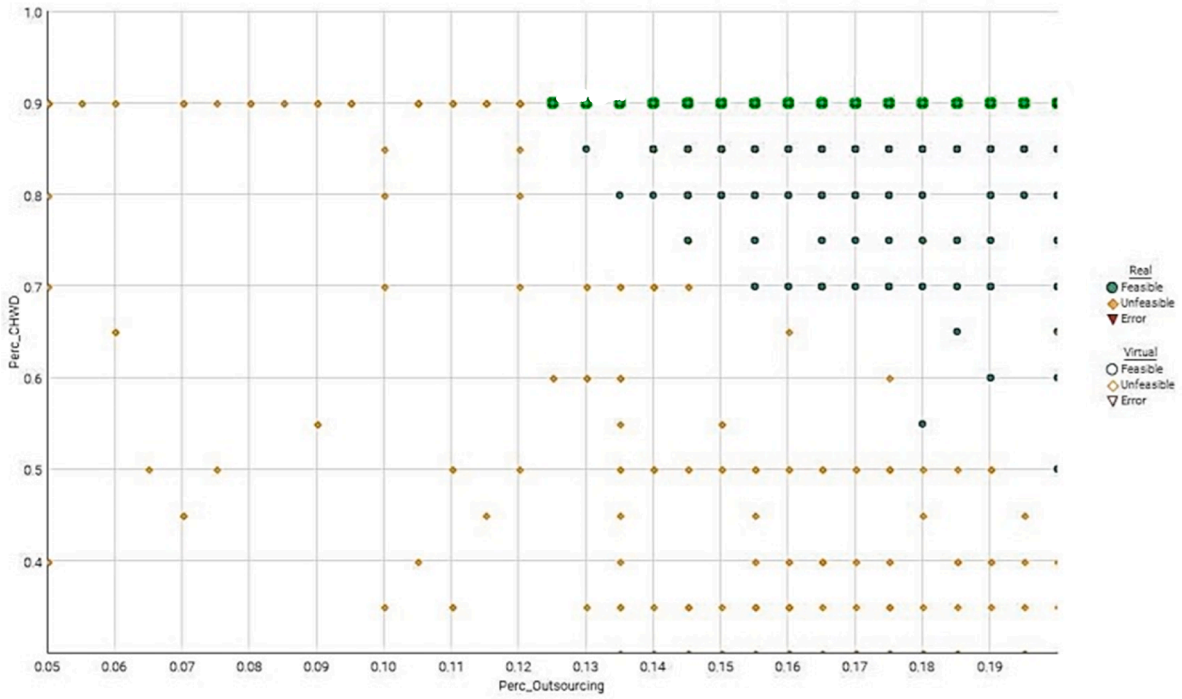

Fig. 5. Relationship between outsourcing percentage and relative share of CHWD services.

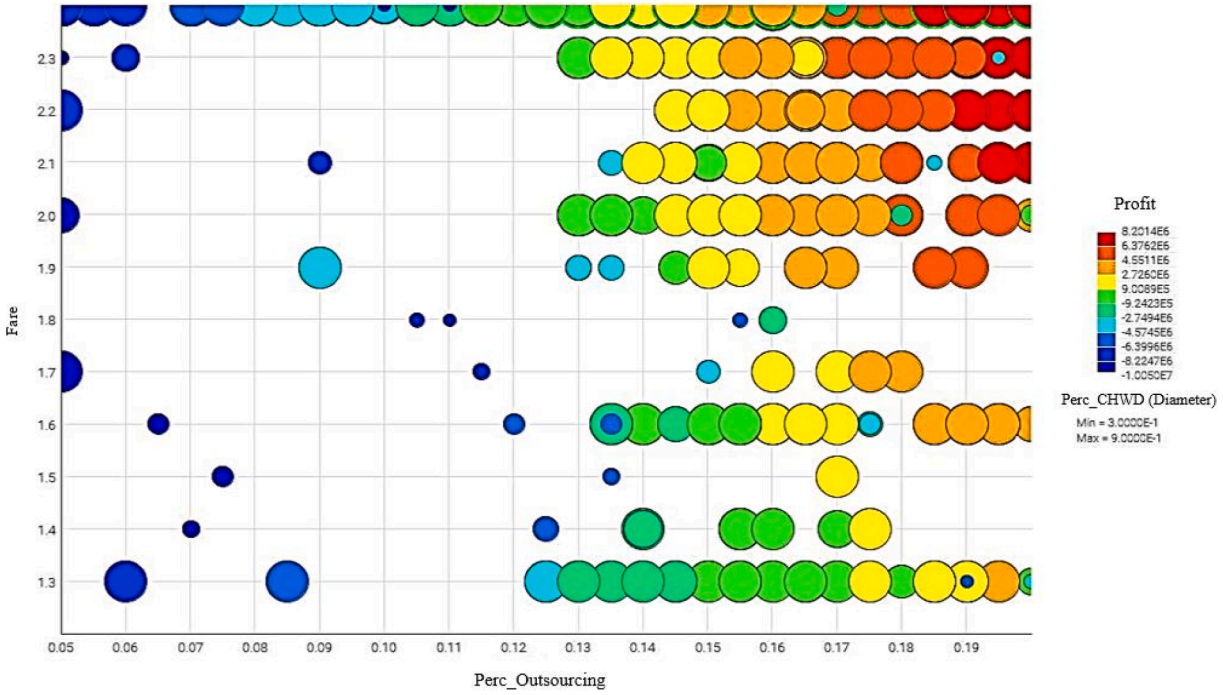

Fig. 6. Relationship between outsourcing percentage and fares.

availability of necessary vehicles on the market, at least in first months of operations after the disruption.

The expected impacts on the monthly cash flow mainly rely on two beneficial effects. On one side, the reduction of costs obtainable thanks to the lower unit cost for the distances which are intended to be travelled by subcontracted bus services in general and, to a greater extent, by CHWD services. On the other side, the increase in revenues given by both a higher number of travelling passengers, motivated by an enhancement of their security perception when using less crowded and sanitized CHWD services, and by higher fares for this specific type of service (the demand-fare elasticity has been considered through a simple function according to [37]). A proof of the willingness to pay extra for a safer and cleaner travel option was captured through a survey conducted in [38], which, with reference to the Indian context, suggests the introduction of a personal rapid transit system not only as an advantageous alternative to private vehicles, but also as an efficient solution that can contribute to the creation of a resilient public transport system.

Fig. 3 illustrates the workflow developed within the multiobjective optimization procedure. Input variables are depicted through green icons at the top of the framework, while output variables are are represented by blue rectangles at the bottom. The central point of the workflow is the calculator and the optimization approach.

5. Results

Using a single machine, results have been obtained after performing more than 5000 runs of a specific genetic optimization algorithm (i.e., MOGA-II [39]) which, inspired by the theory of Darwin on the evolution, was able to find at each iteration new individuals representing the population offspring. According to such concept, this latter is supposed to outperform their parents and the selection of the best individuals is based on their fitness to the changing environment, determining their chances to reproduce [40]. The application of the developed multi-objective optimization procedure provided a set of feasible and optimal solutions, which have been then visualized through graphical representations to facilitate the understanding of results. In Fig. 4 only green circles constitute feasible outcomes and correspond to profit values greater than 0. In this context, a minimum percentage of outsourced services equallings to 12.5% is needed; this latter percentage increases proportionally with the profit. More than one feasible point exists for each outsourcing percentage because of the other possible decision variables.

The percentage of CHWD services is also relevant and contributes to increase profit. The higher the percentage of outsourcing is, the lower may become the portion of CHWD services allowing feasible solutions (Fig. 5). Analogously to Fig. 4, also in Fig. 5 only the green points correspond to feasible configurations.

6. Discussion

In Section 5, the results obtained by performing the optimization procedure have been displayed in terms of the relationship only between two parameters at time, highlighting the influence of the global outsourcing percentage on the company profit and on the entity of CHWD services to be implemented. However, Fig. 6 constitutes the most interesting graphical visualization of outcomes, as it represents 4-dimension results according to the following 4 variables: the outsourcing percentage is shown on x-axis, the fare for CHWD services is on y-axis, the color of the bubbles refers to profit, while their radius is related to the portion of CHWD services. With respect to the color of the bubbles indicated in the legend of Fig. 6, feasible solutions with positive profits correspond to bubbles referring to the shades of yellow, orange and red. Overall, it can be noticed that the maximum profit may be obtained for higher outsourcing percentages, higher fares (thanks to specific after-Covid-19 demand behavior) and a higher share of CHWD services.

Furthermore, the maximum profit can be estimated by selecting the acceptable fare for CHWD services (y-axis) or the acceptable outsourcing percentage (x-axis). From the results reported in Fig. 6, it can be concluded that CHWD services should be proposed, in order to enable the considered public transport operator to recover from Covid-19 disruption. At a more general content level, such finding is in line with the mobility solutions suggested in previous scientific contributions, in terms of service outsourcing and of the implementation of flexible collective services, but, other than that, this study puts forward a comprehensive optimization methodology which combines technical and financial aspects.

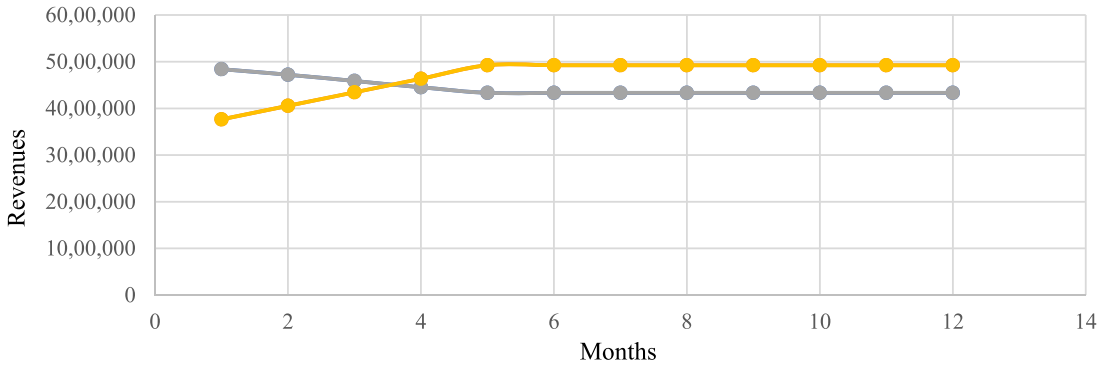

Fig. 7. Break-even point.

Fig. 7 shows in which month after the disruption costs (grey line) and revenues (yellow line) return to be equal. Such kind of result has been obtained for each solution explored in the MDO procedure. The analysis of the break-even point highlights the significance of the time variable in the evaluation of alternative interventions and constitutes an additional advancement of this study as compared to the referenced literature contributions.

7. Conclusions

In front of the impacts of the Covid-19 pandemic on mobility, the paper suggests a decision-support technique to envision the arrangement of possible resilient strategies to ensure the financial survivability of public transport operators in light of the significant demand shock and of the additional users' security requirements. Thanks to the application to a simple case study, the proposed MDO methodology enabled the identification of the most effective managerial solutions aiming at optimizing some conflicting goals, like the maximum positive profit, the minimum outsourcing percentage and the maximum ticket fare for a single trip. The results may be very helpful in reducing also the time to recover, that is another quite relevant issue when facing disruptions. One of the limitations of the developed methodology consists in the adoption of a quite simple demand-fare elasticity function, which could be addressed in the future developments of the study by administering a survey to capture more precisely users' willingness to pay with reference to the considered context. This investigation could be paired with a more detailed market analysis to better predict the availability of new vehicles for outsourcing services and, thus, the evolution of the transport company profit. Furthermore, the analysis of the break-even point could be included in the optimization procedure, so as to identify the alternative solutions ensuring also the shortest time recovery. Nevertheless, the study enables to formulate some useful policy recommendations to the main stakeholders involved in public transport, i.e., on one side, the operators and, on the other side, the administrative entities regulating such field. The former are advised to enhance their readiness to undertake a more flexible planning and management of services so as to adapt and strengthen their position in the face of unpredictable environmental changes. To this end, the latter should complement the efforts of operators with economic and legislative assistance leading to an overall sustainable mobility system.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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