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A model for optimal bus routes packaging in a competitive contracting environment: A case study of Tehran

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A R T I C L E I N F O

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A B S T R A C T

Transit authorities often prefer to outsource the bus routes to the private sector through a competitive tendering or negotiation procedure. A major challenge for decision-makers in this area is the optimal arrangement of routes among contracts which directly impacts the operating costs, labor costs, vehicle resources, level of competition between private operators, required subsidy, contract price, and system efficiency. Therefore, this study proposes a new model to find optimal route packages considering the parameters including package size, package revenue, the geographic distribution of routes, and terminal locations. The methodology relies on a genetic algorithm equipped with innovative methods, making it applicable to large-scale urban networks. We programmed both the model and the solution approach in C++ programming language and applied them to the city of Tehran as a real case study, which involved 169 routes and 2,215 bus fleets. In the main scenario, 10 packages were identified and compared with the current packages. The results demonstrated a 7.6% reduction in revenue deviation among the packages, indicating improved balance. Additionally, the routes within each package exhibited geographical concentration, aligning with the common terminal approach. By applying the proposed methodology to the bus network in Tehran, the study highlights the potential of the model in outsourcing bus routes to the private sector in similar real-world practices. It is worth noting that the Tehran Bus Organization has utilized the proposed packages derived from this study in their recent tender processes. Evaluation of the new packages' effectiveness demonstrated a notable decrease of 17% in average bid prices. This reduction directly corresponds to a decrease in operating costs and the required subsidy.

1. Introduction

Outsourcing bus routes to the private sector is a general decision made by most transit authorities around the world to reduce operating costs and optimize human and vehicle resources (Hensher, 2007). The research studies in this field and their solutions to reduce costs can be divided into two general categories: 1- service design and optimizing parameters such as required fleets and frequencies, 2- the contracting mechanism and its components. Studies have been conducted on the first category mainly focus on issues like the optimal bus network design (Baaj and Mahmassani, 1995; Cipriani, Gori and Petrelli, 2012; Ceder, 2015; Huang et al., 2020) and determining the optimal frequency and number of vehicles (Afandizadeh et al., 2013; Laporte et al., 2017; Buba and Lee, 2018). There are far fewer studies in the second category that focus more on issues such as the contract mechanism, contract duration, competitive tendering, incentive schemes, and service quality (Rojo et al., 2015; Sheng and Meng, 2020). But even in this category, a few studies have paid attention to the optimal arrangement of bus routes among packages, which can significantly impact operating costs and contract price.

The methods for contracting bus services can be broadly categorized into two main types: competitive tendering (CT) and negotiated contracts (NC). Numerous studies have compared the experiences of using CT and NC methods in cities worldwide and have discussed their respective impacts on cost reduction (Filippini et al., 2015; Pedro and Macário, 2016; Rosell, 2017; Wallis, 2020). In the CT method, bus routes are divided into bid packages and private operators are selected through a tendering process. The transit authority sets requirements for fares and service quality in the contract (Mouwen and van Ommeren, 2016). On the other hand, the NC method involves the transit authority selecting private operators through negotiation, and competition is based on financial incentives specified in the contract, as well as the operator's performance (Hensher and Stanley, 2003).

In recent decades, the CT method has been preferred in many

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countries such as the United Kingdom (Amaral et al., 2013), Singapore (Leong et al., 2016), Turkey (Canıtez et al., 2019), and Germany (Beck, 2011). Bray and Wallis (2008) examined the bus contracts reform to CT model in some Australian cities and discussed the relevant benefits such as reduction in costs and higher competition. Wallis (2020) analyzed both CT and NC bus contracts in Auckland and Wellington as two largest metropolitan cities in New Zealand. He showed that the gross costs in the NC contracts are 10–15% higher in Auckland and 30–35% higher in Wellington compared to the CT contracts. Alexandersson et al. (1998) showed that the average cost per kilometer decreased by 7 percent after eight years of a CT approach in Sweden's bus services. Ida and Talit (2017, 2018) discussed the effect of reforms in bus service contracts from two monopolies to a competitive tendering environment in Israel. They proved that such a reform succeeds in improving service levels, subsidies, and passenger volume. However, some other studies believe that CT is not necessarily the most appropriate method for public transport contracts, because NC leads to higher service quality and passenger growth (Hensher and Stanley, 2010; Kavanagh, 2016). Also, the negotiation method has more flexibility and can adapt to unpredictable conditions during the contract period (Hensher, 2007). There is no consensus on the most suitable method due to different local policies and economic conditions in different countries (Sheng and Meng, 2020).

Some other studies have worked on important elements and structural features of bus service contracts (Hensher, 2007; Iseki, 2010; Croissant et al., 2013). Contract duration, contract size, and incentive schemes are the most important elements. Cambini and Filippini (2003) analyzed the optimal area size for a CT approach by using empirical results in the Italian bus industry. They showed that political issues such as provincial area are more important than economies of scale and density in defining the size of area. Veeneman et al. (2007) explained the advantages and disadvantages of net-cost and gross-cost contracts in the Netherlands bus sector over eight years and discussed the results of different penalty and incentive scheme. White and Tough (1995) analyzed 380 bus services contracts in four local authorities in Britain based on cost per mile index. They showed that a gross-cost contract is often more cost-effective than a net-cost contract. Kennedy (Kennedy, 1995b, 1995a) estimated the welfare impact and cost savings of London bus tendering in two scenarios: one based on total cost savings and the other based on net cost savings excluding wage reductions from the calculations. Sheng et al. (2021) proposed a leader–follower game model to determine the optimal incentive scheme and penalties in bus services contracts.

Hensher and Stanley (2010) and Gordon et al. (2013) discussed that short-term contracts (1 to 3 years) promote a better competition while long-term contracts (7 to 10 years) encourage the private operators for investment and innovation. Hensher and Houghton (2004) examined the impact of various financial incentives on the performance of private operators. Rojo et al. (2015) concluded that private operators could attract new passengers on bus routes by incentive schemes, which would reduce the required subsidies. Mouwen and van Ommeren (2016) investigated the data of various contracts of public transportation and studied the effect of competitive tendering on costs and subsidies. Lieberherr and Leiren (2017) investigated the relationship between different methods of privatization and public service quality for two different cases. Shen and Feng (2020) examined the impact of four different subsidy policies on service quality and passenger volume of bus routes in China.

Other important elements of bus services contract are the number of routes and fleet size. The number of routes can range from one route to the entire network. Smaller contracts lead to the participation of small operators and increase competition in the market (Fox, 2000). On the other hand, larger contracts could lead to a better technical management, easier monitoring schemes, and further reduction in total costs. Chowdhury et al. (2006) presented a mathematical model for optimal bus route packaging in their study. The objective function is defined by three weighted terms including package size, package revenue, and geographical overlap of routes in each package. They assumed the same fleet size for all packages in their proposed model. Also, the geographical distribution of routes is only based on the common-corridors approach. Nayan and Wang (2017) have also proposed a mathematical model for optimal route packaging. The main parameters in their study include bus ownership, parking costs, the cost of waiting time and total distance coverage by each package. The solution method is based on a mixed-integer nonlinear programming approach that is applied for a numerical example. They did not discuss possibility of using the method for large-scale real networks. Also, the geographical overlap of routes and package revenue are not considered in their studied model.

The literature review reveals that several studies have examined different aspects of bus route contracting, with a focus on comparing CT and NC contracts, contract duration, payment methods, performance measurement, financial incentives, and service design. However, only a few studies have specifically addressed the optimal arrangement of routes among packages before contracting. Additionally, to the best of our knowledge, there are only two existing studies (Chowdhury et al., 2006; Nayan and Wang, 2017) that have proposed mathematical models for the optimal packaging of bus routes. The novelty of our study is: We defined a new objective function and mathematical model that capture the real situation in a more comprehensive manner. Moreover, we have applied the common-terminal approach for the first time, which proves to be more effective in reducing costs compared to the common-corridor approach. The solution approach and modeling framework are programmed in the C++ environment, making it easily applicable to networks of any scale. We applied the proposed methodology to the city of Tehran as a large-scale network with a population of 12 million. The results will be discussed in Section 4.

2. Problem formulation and methodology

2.1. Main parameters

This section defines and explains the main parameters that are used in the process of modeling and solving the defined problem. A mathematical model of the problem will then be presented.

2.1.1. Geographic distribution of routes

Geographic distribution of routes among packages has a great impact on reducing private-sector costs in the process of operation, monitoring, labor and vehicle resources. There are generally two approaches to packing routes: 1- Common or close corridors in a specific area and 2- Common or close terminals approach.

In previous studies, the first approach has been used because it is easier to implement. In this approach, the city is simply divided into independent areas and then the adjacent routes in each area are placed in a package. The amount of overlap between packages should be minimal regardless of the terminal locations. In the second approach, routes that have a common terminal are included in a package. In a large-scale network, several nearby terminals and corresponding routes may be placed in one package. Contrary to the first approach, routes in a single package do not necessarily have a common corridor, but they all start from one or more nearby terminals.

From an operational point of view, the second approach is much more attractive to private operators and will reduce costs for the following reasons:

- They can carry out monitoring operations through a single person at each terminal.
- The backup fleet at the terminal can be used for all routes, so the number of backup vehicles is greatly reduced, which will directly reduce the costs of the private operator.
- There are no common terminals between different packages, which leads to the enhanced monitoring of route performance and reduces conflict between operators.

- The operator can store the buses in a location close to the terminal, which will reduce the time and cost of moving the vehicles between the terminal and the depot.

In this study, we have used a combination of both approaches with the priority of the common terminal approach. In the first step, close terminals are grouped based on the desired number of packages. Accordingly, the city is divided into independent areas. GIS software (Geographic Information System) and its tools have been used to apply this step. Finally, by considering other indicators (package size, package revenue and common corridor between the lines) and using the genetic algorithm, the routes are distributed between the packages.

It should be noted that in most routes, there are two terminals at the beginning and end of the route; so there are two options for allocating the routes to the packages. Therefore, the problem will be in order 2^n where n is the total number of routes.

2.1.2. Package revenue per bus

If the revenue gap between packages is minimized, revenue is more likely to be fairly distributed among operators and a better competitive environment will be created. In this article, we select package revenue per bus as a proper index, which is equal to the total revenue divided by the number of buses in a single package. This index is the best choice for comparison due to the various sizes of packages. It should be noted that the term “revenue” means the direct revenue from the fares and doesn’t include the subsidy. The point is that optimal route packaging will reduce the total required subsidy due to the reduction of total operational cost.

2.1.3. Package size

If the package size is too large, it will result in a smaller number of packages, leading to reduced competition among private operators. On the other hand, small packages increase the overall number of packages and consequently allow for a higher number of operators to participate. However, this approach has two significant disadvantages:

1) Since many private operator costs such as the staff salaries are independent of fleet size, the bid price will be increased in tenders.
2) As the number of private operators increases, it will become more difficult for the public regulator to monitor and control them.

Another point in this regard is the size of packages compared to each other, which can be equal or different. In our proposed model, the optimal packages can have different sizes, and therefore all kinds of big, small and new operators can participate. It should be noted that finding small packages of the same size from the beginning and combining them to form larger packages can lead to a reduction in the objective function. For example, let’s consider a terminal with 5 routes and 70 buses. If the package sizes are restricted to be between 40 and 50 buses, some of the routes of this terminal will be included in another package, and an optimal combination will not be proposed. By highlighting the importance of flexibility in package sizes and considering various factors such as income levels, the model can provide more robust and optimal results.

2.2. The mathematical model of problem

The definition of variables needed to formulate the problem in this study is as follows:

K: Set of packages.

R: Set of routes.

n: Number of routes.

m: Number of packages.

x_r^k: Is a binary decision variable; the value will be one, if the route r exists in package k or zero if it doesn’t.

I_r: The daily revenue of a bus on route r (the number of passengers multiplied by the fare rate).

I_k: The average daily revenue of a bus in package k.

P_r: Number of daily passengers on route r.

$Fare_r$: The value of fare on route r.

N_r: Number of buses on route r.

FS_k: Fleet size of package k.

FS_{min}: Minimum fleet size per package.

FS_{max}: Maximum fleet size per package.

FS_{avg}: Average fleet size of packages.

FS_{total}: Number of total available buses in the city.

I_{avg}: The average daily revenue of a bus in the network (total revenue divided by total fleet size).

D_r^k: The length of the segment of Route r that is in the area of package k.

$\alpha_1, \alpha_2, \alpha_3$: The weighting factors that bus regulator can determine them based on the importance of three main terms of the objective function. In Tehran, we assumed a higher weight for the revenue parameter, because the financial issues are more important for both regulator and operator.

γ, β: The monetary values to convert unit difference in the objective function. Therefore, the objective function is expressed in units of Rials. The revenue term in the objective function doesn’t need a monetary factor because the unit of this term is Rials.

τ: Maximum allowable deviation from the I_{avg}

In this study, we assumed that the service-design step had already been done and the problem is to find the optimal distribution of routes among packages. Therefore, the specifications of each route including the path, number of buses, and passengers are predetermined and will be entered as input. Some other assumptions are also made as follows:

- We assume a maximum and a minimum limit for the package size to avoid the formation of too large and small packages. These limits can be determined based on the number of vehicles owned by existing private operators.
- The desired number of packages is pre-determined by the regulator based on issues such as the level of competition and terminals distribution in the city. However, we used a reasonable approach to estimate the desirable number of packages in Tehran: divide the fleet size of network by the average fleet size of existing operators.
- Each route can only be assigned to one package.
- The type of contract is a net-cost contract.
- The ownership of all terminals and depots is for the public sector, so there is no advantage for the bidders regarding this issue.

According to the defined problem in this study and the above assumptions, the mathematical model of the objective function and constraints is as follows:

$$\text{minimize} Z = \alpha_1 \sum_k \sum_r \left| x_r^k I_r - I_{avg} \right| + \alpha_2 \sum_k \sum_r \beta \left| x_r^k N_r - FS_{avg} \right| - \alpha_3 \sum_k \sum_r \gamma x_r^k D_r^k \quad (1)$$

Subject to:

$$FS_{min} \le FS_k \le FS_{max}, \forall k \in K \quad (2)$$

$$\sum_k FS_k = FS_{total} \forall k \in K \quad (3)$$

$$(1-\tau) I_{avg} \le I_k \le (1+\tau) I_{avg} \forall k \in K \quad (4)$$

$$\sum_k x_r^k = 1 \forall r \in R, x_r^k = \{0,1\} \quad (5)$$

$$I_r = P_r Fare_r \forall r \in R \quad (6)$$

Equation (1) is the objective function of the model, which has three main terms. It can be said that this function aims to distribute the routes

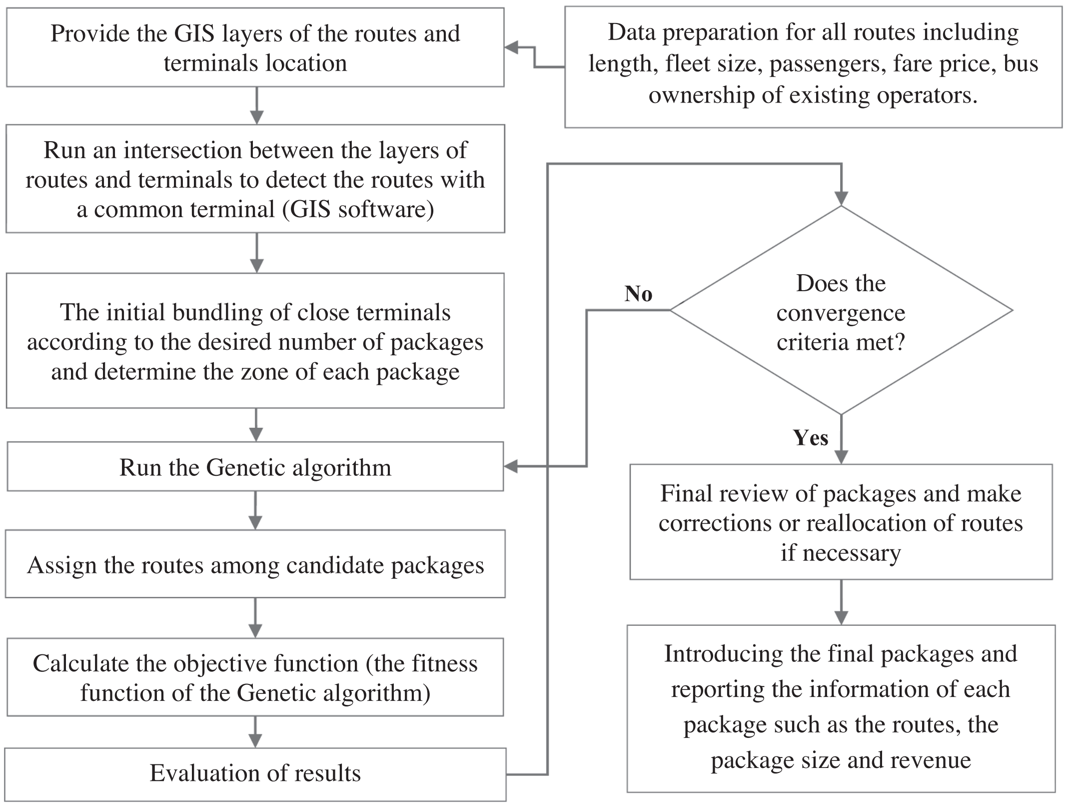

Fig. 1. Steps of proposed solution approach.

as fairly as possible between packages. The first term captures the difference in revenue of each package from the average revenue of a bus between all packages. The second term minimizes the difference in fleet size of each package from the average fleet size. The third term seeks to select a package for each route that has the most length coverage along that route.

Constraint (2) ensures that the number of buses in each package does not exceed the minimum and maximum fleet size. Constraint (3) guarantees that the total available fleet will be distributed among all packages. Constraint (4) controls the maximum revenue deviation of a bus in each package of average bus revenue. Constraint (5) ensures that each route can only be assigned to a specific package. Equation (6) defines how to calculate the fare revenue for each route.

3. The solution approach and methodology

The solution approach and solving steps for the defined problem are presented in Fig. 1. In the following, details of the main steps will be discussed.

3.1. Data preparation

We need three categories of data for the defined problem in this study:

1- The data of existing routes in the city including length, number of vehicles, passengers and etc.

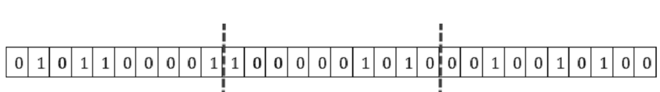

Fig. 2. An example of chromosome structure.

2- The information of existing private operators such as the vehicle capacity, vehicle ownership, location, and specifications of current packages.

3- Geographical location of routes and terminals. To run the model for Tehran, we provided this information from the database of Tehran Bus Organization (TBO) in the form of GIS layers.

3.2. Grouping of close terminals and determination the area of each package

As mentioned before, we used GIS software at this stage. The shape files of the existing terminals and routes are prepared and the closed terminals are then grouped according to the desired number of packages. The main parameters for terminal grouping are the geographic distance between the terminals and the current municipal boundaries in the city. For the city of Tehran as a case study, 52 terminals and 169 bus routes were identified. Besides, we assumed that the desired number of packages is 10, so the close terminals are divided into 10 groups (Fig. 5 in the case study section).

In the next step, using the intersection function and other tools in GIS software, routes with a common terminal are identified. There are three types of routes here; routes with both sides in terminals, routes with one side in terminals, and routes with no sides in terminals. Most routes are in the first category, which means that there are two options for selecting the package. Next, the genetic algorithm will be implemented for the optimal distribution of routes between packages.

3.3. Run the Genetic Algorithm

Considering the problem order of 2^n and to make it possible for running in a real large-scale city, we used a genetic algorithm in the optimization procedure in this study. Each chromosome represents a state of distribution of all routes between packages and is defined by a binary vector of zeros and ones. Each gene is defined as a binary variable

Table 1
The specifications of current packages in Tehran.

Package ID	Number of Routes	Total Routes length(km)	Daily distance covered (km)	Daily passenger	Daily revenue (Rials[a])	Fleet size	Revenue per bus (Rials)
1	10	117	11,192	36,576	530,822,787	145	3,660,847
2	8	75	9,384	31,528	370,591,717	110	3,369,016
3	19	230	22,474	51,027	679,279,522	226	3,005,662
4	13	149	17,038	55,487	750,586,309	183	4,101,565
5	8	118	9,560	24,457	326,949,817	111	2,945,494
6	22	286	27,792	73,997	1,032,886,328	318	3,248,070
7	7	148	11,604	18,561	295,626,230	98	3,016,594
8	24	299	27,911	69,753	939,256,523	307	3,059,468
9	8	74	11,748	43,178	497,897,781	131	3,800,746
10	7	73	7,376	23,627	314,296,231	92	3,416,263
11	15	171	17,175	39,027	534,112,573	183	2,918,648
12	7	101	7,396	16,556	226,745,136	76	2,983,489
13	15	159	13,946	39,992	517,558,901	165	3,136,721
14	6	79	8,855	11,254	159,413,695	70	2,277,338
Sum	169	2,077	203,451	535,020	7,176,023,551	2,215	_
Average	12	148	14,532	38,216	512,573,111	158	3,209,994

[a] Rials: is the currency of Iran.

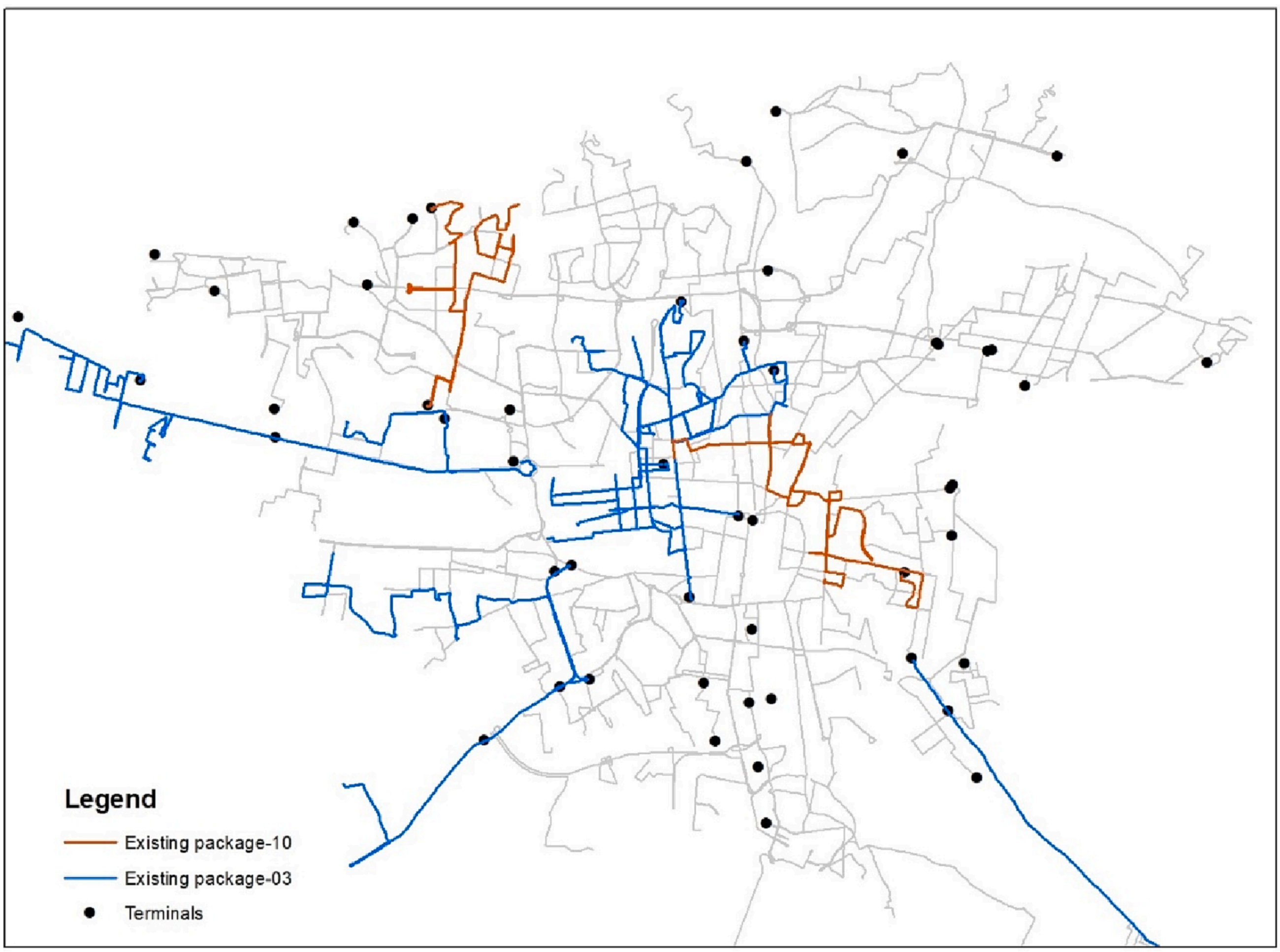

Fig. 3. The geographical location of existing packages (Packages 3 and 10).

(x_r^k) that is equal to 1 if the route r is selected for package k, otherwise, it is zero. A hypothetical example of chromosome structure for 10 bus routes and 3 packages is shown in Fig. 2. The vertical dash lines separate the packages from each other.

It should be noted that the fitness function of the genetic algorithm is the same as the objective function presented in Equation (1). The convergence criterion is that the objective function does not change significantly. Implementation of genetic algorithm and optimization process was done through a C++ code for the city of Tehran as a large-scale network.

4. Case study (City of Tehran)

Tehran is the capital of Iran with over 12 million population. The

Table 2
The specifications of optimal packages in scenario 1.

Package ID	Number of Routes	Total Routes length(km)	Daily distance covered (km)	Daily passenger	Daily revenue (Rials)	Fleet size	Revenue per bus (Rials)
1	10	130	10,869	26,447	382,614,659	116	3,298,402
2	12	164	13,071	31,974	427,104,346	151	2,828,506
3	10	129	15,742	38,112	532,919,568	151	3,529,269
4	20	254	22,170	47,680	666,400,323	219	3,042,924
5	7	92	9,405	22,252	311,875,949	103	3,027,922
6	9	188	15,251	22,216	353,945,861	123	2,877,609
7	9	124	14,151	27,427	403,104,930	130	3,100,807
8	19	208	16,499	41,842	550,385,228	205	2,684,806
9	17	232	23,848	53,559	775,632,033	231	3,357,714
10	20	178	20,019	79,675	952,830,722	267	3,568,654
11	8	87	12,900	38,378	462,364,791	139	3,326,365
12	11	113	13,244	51,289	655,359,257	170	3,855,054
13	7	85	8,285	23,237	314,108,737	93	3,377,513
14	10	93	7,996	30,932	387,377,147	117	3,310,916
Sum	169	2,077	203,451	535,020	7,176,023,551	2,215	_
Average	12	148	14,532	38,216	512,573,111	158	3,227,604

Table 3
The specifications of optimal packages in scenario 2.

Package ID	Number of Routes	Total Routes length(km)	Daily distance covered (km)	Daily passenger	Daily revenue (Rials)	Fleet size	Revenue per bus (Rials)
1	11	145	12,203	27,327	396,157,702	126	3,144,109
2	15	205	16,415	44,374	609,866,950	199	3,064,658
3	19	220	29,155	77,060	997,129,383	297	3,357,338
4	28	342	31,103	74,411	1,007,308,187	323	3,118,601
5	12	152	14,584	37,303	510,219,320	162	3,149,502
6	10	204	16,980	23,994	381,365,490	137	2,783,690
7	8	108	12,421	25,649	375,685,302	116	3,238,666
8	20	187	15,994	61,720	770,919,955	229	3,366,463
9	21	283	28,523	63,809	923,368,696	281	3,286,010
10	25	231	26,072	99,373	1,204,002,567	345	3,489,863
Sum	169	2,077	203,451	535,020	7,176,023,551	2,215	_
Average	17	208	20,345	53,502	717,602,355	222	3,199,890

current bus network has 169 routes, 52 terminals, and 2215 vehicles that are outsourced to the private sector (BRT routes are still managed by the public sector). The routes have been outsourced in the form of 14 packages to 14 different operators. The specifications of current packages and some indices are presented in Table 1. Comparing the revenue of a bus in the last column of this table shows that there is a big difference between packages. For example, the revenue of a bus in package 4 is 80% more than package 14. The deviation rate from the average revenue among current packages (coefficient of variation) is about 13.4%. In Fig. 3, the geographical allocation of routes is shown for two packages as an example. It can be seen that the routes in both packages are geographically dispersed which has increased the costs of private operators such as labor, vehicles, and monitoring costs.

To implement the proposed model on real data that were collected in Tehran and to determine the optimal packages, we considered two scenarios. In the first scenario, the desired number of packages is the

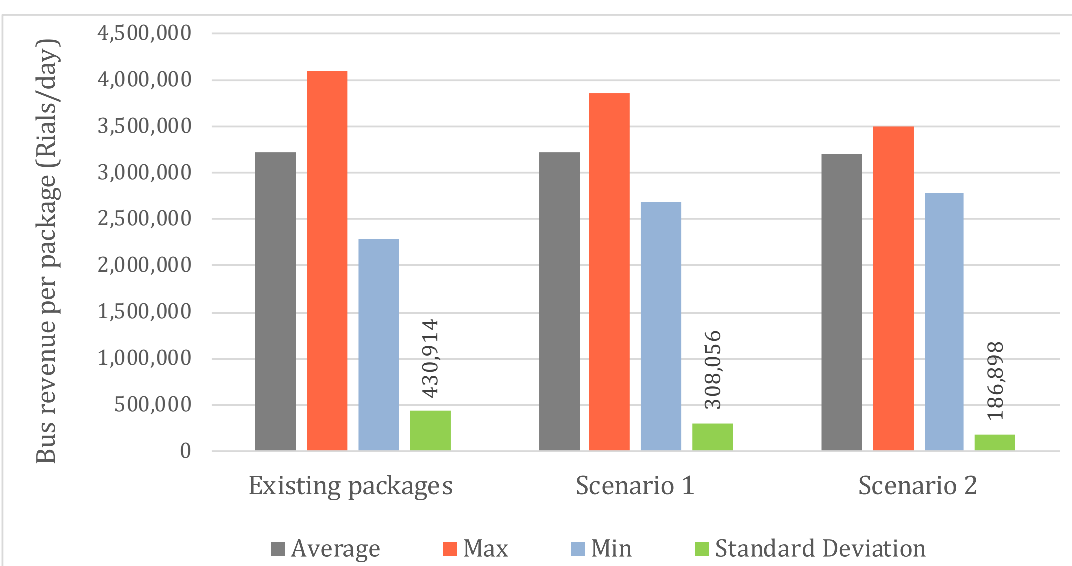

Fig. 4. Statistical analysis of package revenue per bus.

Fig. 5. The geographical location of optimal packages in scenario 2.

same as the current situation and equal to 14 packages. This scenario allows comparison with the current situation. In the second scenario, the desired number of packages is assumed to be 10 based on the average number of fleets owned by existing operators and the total available fleets. Also, the following assumptions were made before the runs:

- The minimum and maximum number of buses for a single package are assumed to be 70 and 350, respectively for both scenarios. These values were specified according to the number of fleets owned by existing operators and their potential.
- $\gamma = 2500(Rials)$ and $\beta = 1800(Rials)$
- The weighting factors are assumed as follows: $\alpha_1 = 2$, $\alpha_2 = 1$ and$\alpha_3 = 1$ (higher weight for the revenue term in objective function).

Using GIS software and creating an intersection between the terminal and routes layers, we realized that there are 115 routes with both sides in the terminal, 38 routes with one side in the terminal, and 16 routes with no side in the terminal.

4.1. Results of Runs and Discussion

For each scenario, we simulated the proposed methodology within the genetic algorithm code for several runs and the best answer with the best value of the objective function was selected as the optimal bid packages. The results and characteristics of the final packages for scenario 1 and scenario 2 are presented in Table 2 and Table 3 respectively. In these tables, the number of routes, fleet size, passengers, and revenue of a bus are reported for every single package. Also, the results of comparing the "package revenue per bus" between the two scenarios and the current situation are shown in Fig. 4.

As mentioned before, the main scenario for running in real conditions is the second scenario for the following reasons:

- There are many private operators in Tehran that have the ability to supply about 200 to 250 buses. Therefore, considering that the total number of required fleets is equal to 2215 buses, the desired number of 10 packages is a reasonable value.
- Reducing the number of packages while maintaining a competitive environment (a variety of package sizes), will certainly lead to a significant reduction in the bid prices offered by private operators.

The smallest and largest size of packages in scenario 2 are 116 and 345 respectively, which is consistent with initial assumptions. The maximum and the minimum values of package revenue per bus are 3,489,863 Rials (package No. 10) and 2,783,690 Rials (package No. 6) respectively, which have only 20% difference as a worst-case (In the existing packages in Tehran, this difference is 80%).

According to Fig. 4, the standard deviation index values have decreased from 430,914 in the current situation to 308,056 in Scenario 1 and 186,898 in Scenario 2. This indicates that there has been a significant improvement in the fair distribution of revenue between packages, with an increase of 28.5% in Scenario 1 and 56.5% in Scenario 2. These improvements hold particular importance for private operators who heavily rely on daily revenue. Additionally, when comparing the coefficient of variation index, the revenue variation has decreased from 13.4% in the existing packages to 9.5% in Scenario 1 and 5.8% in Scenario 2.

Fig. 5 illustrates the geographical distribution of the proposed packages and the final configuration of routes and terminals in scenario 2. The figure is divided into two subfigures to enhance visibility. It is apparent that the routes are more concentrated compared to the current situation. Additionally, in contrast to the existing arrangement, this study adopts an approach where nearby terminals are grouped and assigned to specific packages. The labels of terminals in Fig. 5 indicate the corresponding package numbers to which they are assigned. Importantly, there are no shared terminals among different packages, which is highly favorable for private operators as it minimizes potential conflicts between them.

5. Conclusion

The optimal packaging of bus routes has an essential role in the fair distribution of revenues, creating a competitive environment, and reducing the total costs of the entire system. To formulate the problem and determine the optimal packages, this research proposed a new mathematical model with three main parameters including package revenue, fleet size, and the geographical distributions of routes. Moreover, we considered the common terminal approach for the first time in this study, while the previous studies only considered the existence of a common corridor between the routes in a single package.

We applied the proposed model and methodology to the city of Tehran through two scenarios: In the first scenario, the desired number of packages was equal to the current situation and the comparison was performed under the same conditions. This scenario illustrated that the proposed methodology works properly and improves the current indicators. The coefficient of variation of bus revenue among packages decreased from 13.4% in the current situation to 9.5% in the proposed packages, indicating a notable improvement. The second scenario, referred to as the target scenario, involved 10 desired packages. The coefficient of variation of bus revenue decreased even more in scenario 2 and reached to 5.8% which is a significant improvement. Furthermore, the geographical distribution of routes among the proposed packages exhibited a substantial improvement compared to the current packages in Tehran.

The utilization of common terminals in route packaging leads to cost reduction for private operators, including labor resources, backup buses, and supervision. Consequently, this reduction contributes to a decrease in contract prices. The proposed method outlined in this study is flexible and can be employed by any transit authority to address the challenge of optimal bid packaging.

We provided the results of this research to the Tehran Bus Organization and they used the packages derived from this study in the recent tender. Before using the results of this study, the offered prices for 169 routes in 14 packages with the entry of 22 private operators was 3,100 billion Rials. However, after implementing the second scenario of this study, there was a significant 17% reduction in bid prices. This reduction was achieved while maintaining the same number of routes, a similar number of buses, and the participation of 19 private operators.

CRediT authorship contribution statement

Shahriar Afandizadeh Zargari: Conceptualization, Methodology, Validation, Investigation, Supervision, Writing – review & editing. **Yaser Taghizadeh:** Software, Formal analysis, Writing – original draft, Methodology, Investigation, Writing – review & editing.

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.

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