Use of electric vehicles in carsharing to serve the sports events

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Abstract. Carsharing was appeared at the beginning of the last century with the idea of offering cars for rent. The subsequent development of rental allowed carsharing to take shape as an independent direction in 1971 and in 1991 the European car sharing Association was established. Further computerization made this service more accessible. However, in 1992 the European Union introduced the Euro-1 environmental standard. Further tightening of environmental standards has forced firms to take a fresh look at the provision of carsharing services. As a result, owners were turned to cars with hybrid, hydrogen and electric motors. Due to significant progress in increasing battery capacity the electric vehicles are the most promising for this field of activity. However, the issues of placing charging stations in places where electric vehicles are used intensively in order to provide quick access and reduce waiting times in the queue are still not fully worked out.

1 Introduction

The short-term car rental system started working in Moscow more than 5 years ago and now its fleet consists of more than 25 thousand cars. Carsharing users in Moscow have made more than 110 million trips over the years. At the beginning of this year Russian carsharing took the second place in the world in terms of fleet size. The target audience of carsharing services is young and middle-aged residents of megacities who prefer self-driving to taxi services and, at the same time, strive to save on trips. According to the carsharing company BelkaCar’s information the service is mainly used by men 25-35 years old. This age group coincides with the audience of the most active fans of various sports competitions, primarily football and hockey. The popularity of carsharing among fans is evidenced by the fact that in 2018 – when the world Cup was held in Russia – foreign tourists were allowed to use carsharing services. Fans and tourists were able to rent a car and drive, for example, to the stadiums and attractions of the capital.

However, one of the limiting factors for the development of carsharing is the problem of a sufficiently high level of car engine emissions. Therefore, it is impossible – even if the popularity of this type of service is constantly growing – to endlessly increase the burden...
on the city's ecology. The way out of this situation is seen in the use of electric vehicles for organizations that provide carsharing services.

Since the moment when electric vehicles have been getting a significant increase in their range more and more Russian [1-2] and foreign specialists [3-6] are inclined to use them in the field of carsharing. This is due, among other things, to the simplification of their maintenance, reduction of operating costs associated with the use of fuel and lubricants and high environmental indicators which is especially important in large cities [7-8]. At the same time, serious attention is paid to planning the use of electric vehicles as part of carsharing and other types of short-term car rentals [9].

Figure 1 shows the financial statements of the carsharing company LLC "ANYTIME" for 2016 which includes expenses of 300 rubles and 100 rubles per car per month including lubricants and cooling as well as their re-lubrication. The cost of these items will amount to about 5 million rubles a year with a declared fleet of 1038 cars. When reducing these costs together with reducing the cost of "refueling" the car there is a possibility to make carsharing available to a wider audience of users.

| Charging the number of cars ("v" - purchase; "x" - sale) | Cost of 1 car (rubles) | Amortisation period (months) | Cars' quantity |
|--------------------------------------------------------|------------------------|-----------------------------|---------------|
| Company property (sales)                                 | 680 000                | 36                          |               |
| Company property (purchase by shareholders)              |                        |                             |               |
| Operational leasing company "Entelinn"                    | 2 300 000              |                             | 200           |
| Operational leasing company "Alexander"                  | 24 851,46p.            | 644 332                     | 24            |
| Buying cars with loans                                    |                        | 260%                        |               |
| Investment program 56/30                                  |                        |                             |               |
| Investment program 45/55                                  |                        |                             |               |
| Investment program 06/30                                  |                        |                             |               |
| Investment program "Magistral" (320 559 rubles)           |                        |                             |               |
| Total sum                                                |                        |                             | 200           |

"ANYTIME" BUDGET [2016] | Plan |
|------------------------|------|
| Sum                    | 9 032 373 | 13 731 | 858 | 25 734 |
| Gas                    | 5 985 850 | 9 100  | 858 | 25 734 |
| "ranp fuelling"         | 8 750     | 13 571 | 858 | 25 734 |
| Compensation for gas    | 9 692     | 15    | 858 | 25 734 |
| Compensation for windshield washing liquid                | 70 343    | 1 200  | 858 | 25 734 |
| Car wash              | 1 921 571 | 2 000  | 858 | 25 734 |
| Auto service          | 3 281 893 | 500   | 858 | 25 734 |
| Automobile insurance franchise                            | 2 252 652 | 500 | 858 | 25 734 |
| Reissue of documents | 12 150     | 10    | 858 | 25 734 |
| Inhouse rest         | 65 770     | 100   | 858 | 25 734 |
| Towing truck         | 65 770     | 100   | 858 | 25 734 |
| Consumables (coolant, antifreeze, steering booster liquid, brushes, stickers etc.) | 197 339 | 300 | 858 | 25 734 |
| Tire service        | 218 500     | 100   | 858 | 25 734 |
| Maintenance operation | 42 300     | 200   | 858 | 25 734 |

Fig. 1. Financial statements of LLC «ANYTIME»

2 Methods of estimating distribution of charging stations

When serving fans participating in sports competitions it is necessary to take into account the distribution of sports complexes on the territory of the city where these competitions are held. Consider the territory of the "old" Moscow located within the Moscow MKAD Ring Road where the main sports events are held at the regional, Russian and international level (Fig. 2).
As we can be seen from figure 2 the location of sports complexes on the territory of the city is fairly uniform so electric vehicle charging stations can also be located evenly on this territory.

Fig. 2. Distribution of sports complexes on the territory of "old" Moscow (marked with circles) and the proposed location of charging station (marked with stars)

To avoid the accumulation of electric vehicles at one or two stations we can suggest distributing travel routes according to the traveling salesman's task.

The number of charging stations can be determined from the condition of the charging time of one electric vehicle (about 20 minutes) – it will be the minimum waiting time in the queue for the next customer. These conditions allow to use the complex of queues.

3 Results and Discussion

Using the planned number of attracted vehicles (1308 units) for the provision of carsharing services of LLC "ANYTIME" we can calculate the number of charging points (posts) at each of the stations. Let's calculate the resource's capabilities by setting the following source data:

− complex of queues;
− number of service channels, \( n = 2 \);
− number of requests in the queue, \( m = 1 \);
− input parameter, \( \lambda = 3 \) in hour;
− service-time variable, \( t_{обс} = 20 \) minutes.

It is necessary to determine the number of channels required to ensure the system's operability with probability \( P \geq 0.97 \).

The calculated service indicators for complex of queues are shown in table 1.
Based on the calculation data we can come to the following conclusion: since there can be no denial of service in such systems there is no need to change the number of channels.

Let’s calculate the number of car charging stations based on the conditions that the car’s mileage from charging to charging is about 400 km (less in winter), the average mileage of a carsharing car in Moscow per day is about 55 km [10] with a daily limit of 150 km (https://www.sostav.ru/publication/karsheringovyj-bum-10-voprosov-vladeltsam-karsherservisa-28619.html), and charging stations work around the clock. Then, on average, an electric car must be sent for recharging 1 time in 3 days.

**Table 1.** Descriptors of complex of queues

| №  | Descriptors                                      | Calculated value |
|----|--------------------------------------------------|------------------|
| 1  | Rate of occurrence                               | \( \mu = 3 \)    |
| 2  | Intensity of distributed load                    | \( \rho = \lambda t_{\text{obs}} = 1 \), since \( \rho < 2 \) that many-server process is stable. |
| 3  | The probability that the channel is free (the proportion of standby time for channels) | \( p_0 = 0,33 \), Therefore 33,3% of the time during each hour the channel will be free and the standby time is \( t_{\text{pr}} = 20 \) minutes. The probability that: 1 channel is occupied – \( p_1 = 0,333 \); 2 channels are occupied – \( p_2 = 0,167 \). |
| 4  | Probability of failure (probability that the channel is busy) | \( P_{\text{ok}} = 0 \), because there can be no denial of service in such systems |
| 5  | Probability of servicing incoming requests (probability that the client will be served) | \( Q = p_{\text{obs}} = 1 \) |
| 6  | Average number of channels used for service (average number of channels used), units | \( n_x = \rho = 1 \) |
| 7  | Average number of free channels, units           | \( n_{\text{pr}} = n - n_x = 1 \) |
| 8  | The ratio of channel occupancy service           | \( K_x = n_x/n = 0,5 \), therefore, the system is 50% occupied with maintenance. |
| 9  | Absolute system capacity (intensity of the outgoing flow of served requests), requests/hour | \( A = \lambda = 3 \) |
| 10 | Mean downtime of system, hour                    | \( t_{\text{pr}} = p_{\text{ok}} t_{\text{obs}} = 0 \) |
| 11 | Probability of forming a queue                  | \( P_{\text{och}} = 0,167 \) |
| 12 | Probability of no-queue                         | \( p = 1 - P_{\text{och}} = 1 - 0,167 = 0,833 \) |
| 13 | The probability that you will have to wait for the service to start is equal to the probability that all channels are busy | \( \pi = 0,333 \) |
| 14 | Average number of requests in the queue, units   | \( L_{\text{och}} = 0,333 \) |
| 15 | Mean wait for a request to be served in the queue, hour | \( T_{\text{och}} = 0,111 \) |
| 16 | Average number of serving requests, units       | \( L_{\text{obs}} = \rho = 1 \) |
| 17 | Average number of requests in the system (requests that are already being served and those that are still in the queue and waiting for service), units | \( L_{\text{CQ}} = L_{\text{och}} + L_{\text{obs}} = 1,333 \) |
| 18 | Mean residence time in system, hour              | \( T_{\text{CQ}} = L_{\text{CQ}}/A = 0,444 \) |
| 19 | Number of rejected request per hour, units      | \( \lambda p_1 = 0 \) |
| 20 | Rated capacity of the system, requests/hour     | 6                 |
| 21 | Physical output of the system depends on its rated capacity, % | 50 |

The number of cars that simultaneously require charging batteries and the number of charging stations can be found from the following formula:

\[
N = 1308 \text{ vehicles}/3 \text{ days}/24 \text{ hours} = 18,2, \quad (1)
\]

So, 18-19 vehicles per each hour need to go to charge the batteries. To satisfy these needs we should build 18-19 charging stations because of the time to reach these stations
often could be much more than 1 hour due to, for instance, the gridlocked streets. However, taking into account the low probability of forming a queue (poch = 0.167) as well as the fact that part of vehicle is on service their number can be reduced to 14-15 units for the territory of the "old" Moscow.

Let’s distribute them evenly in three circles of length l1=108.9 km (corresponds to the length of Moscow MKAD Ring Road), l2= 35.1 km (corresponds to the length of Third Ring Road) and l3= 15.6 km (corresponds to the length of Garden Ring-road) on the territory of the city. The average distance between these "circles": Moscow MKAD Ring Road-Third Ring Road – 11 km; Third Ring Road-Garden Ring-road – 3.5 km.

According to the information of the owners of carsharing organizations cars are most often and intensively used in the Garden Ring-road area. So, we can suggest the following scheme for distributing the number of charging stations along these "circles" taking into account the length of routes: Moscow MKAD Ring Road – 4; Third Ring Road – 5; Garden Ring-road – 6 (Fig.2, marked with stars).

Then the distance between stations on Moscow MKAD Ring Road will be 27.2 km; on Third Ring Road – 7 km, on Garden Ring-road – 2.6 km. Assign numbering – for example, clockwise – to stations starting with the "circle" Moscow MKAD Ring Road then Third Ring Road and after that Garden Ring-road. At the same time, it is desirable that the stations of these three "circles" are not located at road interchanges in the same direction (Fig.2). Due to the bi-directional movement of electric vehicles along routes charging points will be accessible both clockwise and counterclockwise. It reduces the length of routes, for example, from charging station 1 to charging station 4 (as well as to station 2) the distance will be 27.2 km but not 81.7 km.

In order to avoid queues at charging stations and maximize coverage of the city's territory we use the method of distributing routes by a carsharing company according to the traveling salesman problem. To do this fill in table 2 using the capabilities of the resource http://galyautdinov.ru/task/zadacha-kommivoyazhera as follows below.

| Table 2. Table for calculating the traveling salesman problem |
|---------------------------------------------------------------|
| Charging station | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|------------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| 1                | M | 27| 57| 57| 15| 13| 20| 21| 22| 19| 22 | 25 | 28 | 16 | 19 |
| 2                | M | 27| 57| 55| 23| 16| 14| 21| 28| 21| 19 | 14 | 17 | 20 | 23 |
| 3                | M | 55| 27| 57| 36| 32| 27| 21| 27| 30| 31 | 26 | 23 | 26 | 28 |
| 4                | M | 27| 55| 27| 18| 25| 32| 24| 17| 20| 23 | 26 | 29 | 22 | 17 |
| 5                | M | 15| 23| 36| 18| 7 | 14| 21| 7 | 4 | 7 | 10 | 13 | 9  | 6  |
| 6                | M | 13| 16| 32| 25| 7 | 14| 21| 6 | 2 | 5 | 8  | 11 | 9  |    |
| 7                | M | 20| 14| 27| 32| 14| 7 | 14| 10| 8 | 5 | 8  | 11 | 13 |    |
| 8                | M | 27| 21| 21| 24| 21| 14| 7 | 7 | 12 | 9 | 6  | 3  | 6  | 9  |
| 9                | M | 22| 28| 27| 17| 21| 14| 7 | 9 | 12 | 6 | 9  | 6  | 6  |    |
| 10               | M | 19| 21| 30| 20| 4 | 6 | 10| 12| 9 | 3 | 6  | 9  | 6  | 3  |
| 11               | M | 22| 19| 31| 23| 7 | 2 | 8 | 9 | 12| 3 | 3  | 6  | 0  | 6  |
| 12               | M | 25| 14| 26| 26| 10| 5 | 5 | 6 | 12 | 6 | 3  | 3  | 6  | 9  |
| 13               | M | 28| 17| 23| 29| 13| 8 | 8 | 3 | 9 | 9 | 6  | 3  | 3  | 0  |
| 14               | M | 16| 20| 26| 22| 9 | 11| 4 | 6 | 6 | 9 | 6  | 3  | 3  | 3  |
| 15               | M | 19| 23| 28| 17| 6 | 9 | 13| 6 | 3 | 6 | 9  | 6  | 3  | 3  |

The problem is solved in 16 steps and the calculated optimal route is shown in figure 3. The total length of the optimal route is 146 kilometers. It means that during the day the mileage of an electric car will not exceed the allowed one (on average – 150 km/day). The electric vehicle will be charged once every three days, as expected above, and all potential charging stations will be covered.
4 Conclusions

Thus, by distributing electric vehicles around the city in the proposed way we get two advantages: optimizing the length of the route between charges and reducing the probability of forming a queue at charging stations. The increasing number of electric vehicles can be compensated by increasing the number of charging points within a single station without increasing their total number in the city.

The transition to an environmentally friendly transport will significantly reduce emissions of harmful substances while the "electric filling" stations themselves will also be environmentally friendly. Foreign fans who come to the competitions in Russia will be more willing to use them because of their desire to protect the environment.

Reducing the cost of maintenance and repair of electric vehicles will reduce the price of passenger transportation services which will expand the number of its consumers.

References

1. N.V. Polishchuk, Trans. Bus. in Russia, 2, 110 (2017)
2. A. Pasko, E-Management, 2, 16 (2019)
3. G. Wielinski, M. Trépanier, C. Morency, Intern. J. Sust. Transp., 11, 161 (2017)
4. H. Muller. World Electr. Veh. J., 8, 609 (2016)
5. S. Haustein, A.F. Jensen, Intern. J. Sust. Transp., 12, 484 (2018)
6. A.J. Icon, K. Laberteaux, R. Clewlow, Intern. J. Sust. Transp., 12, 526 (2018)
7. H.A. Mehrizi, O. Baron, O. Berman, D. Chen, SSRN, June 1, (2018)
8. E. Costa, J. Seixas, G. Costa, T. Turrentine, Intern. J. Sust. Transp., 11, 518 (2017)
9. L. He, H.-Y. Mak, Y. Rong, Z.-J. Shen, SSRN, October 7, (2016)
10. A. Ivanova, Vedomosti, July 06, (2018)