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Research and modeling of the taxi service in small towns

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Abstract. The majority of existing studies are about taxi services of cities. However, taxi services function in small towns too. There are many parameters that differ from cities. These are the life rhythm, temporal and spatial characteristics of taxi routes, and other features. Therefore, mathematical models of taxi services of cities are incorrect for towns. The article obtains the research of taxi orders and the implementation process by months, days and hours. The model of the taxi service was made as a queuing system. Optimal characteristics of the taxi service were found in the concrete town.

Introduction

Taxis play an important role in providing on-demand mobility. The population mobility increases that demands the development of taxi services. This development takes place both in cities and in small towns. Earlier in small towns taxi services did not exist at all. There are many studies about taxi services in cities [1, 2, 3, 4]. Their results are unsuitable for small towns. The purpose of this article is to analyze the functioning and determination of parameters of taxi services in the typical district center. Another purpose is to search for the improving methods of the taxi transportation system.

Analysis of the problem

The analysis is performed on the example of taxi transportation in the town of Zernograd in the Rostov Region (Russian Federation). This town is a typical district center with a population of 30 thousand people. The largest company in the field of taxi services here is a "Troika" taxi service, which belongs to an individual entrepreneur Maxim G. Ignatenko. Transportation is carried out by 16 cars, working on the basis of official permits. Every order for taxi transportation at this enterprise is carried out exclusively by telephone (fixed or mobile), the order is taken by a dispatcher, and each order is recorded in a special register.

The Internet applications for the taxi order type of Uber, Gettaxi, Yandex-taxi types in the town do not work due to the small number of inhabitants, besides such mobile services from points of the Russian legislation view are not entirely legitimate.

The "Troika" company has been working in two shifts. During the day shift (7:00 to 19:00) the transportation is carried out by 12 cars and at the night (19:00 to 7:00) – by 8 cars.

The analysis of the taxi transportation orders distribution was carried out on the basis of primary documents processing (namely the registers).

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We have obtained the data about an average number of orders by the day of the week, months of the year. The results are presented in the form of a flap chart representing the number of orders for each day of the year, broken down by month and by quarters of the year (Figures 1-4).

In each diagram the month of the year corresponds to a particular line type and you can track the changes in demand for taxi services not only in the month but on separate days of the month. At the same time, the distinctive surge in demand during separate days is revealed.

The number of trips especially noticeable increase in official holidays: on the New Year's Eve and New Year's Day, the Orthodox Christmas, March 8 (International Women's Day), February 23 (the Fatherland Defender Day) (Figure 1). However, on the November 4 (National Unity Day) the demand increase is not seen (Figure 4). This indicates the popularity of different holidays in the population. Besides the demand increase on the unofficial holiday dates or weekends close to them such as the October 31 (Halloween) (Figure 4) and February 14 (Valentine's Day) is evident. The order increase is seen on February 15, 16 – Saturday and Sunday (Figure 1).

January has a very uneven demand for transportation as a result of alternating holidays (formal, church and informal), long weekend and working days during the month (Figure 1).

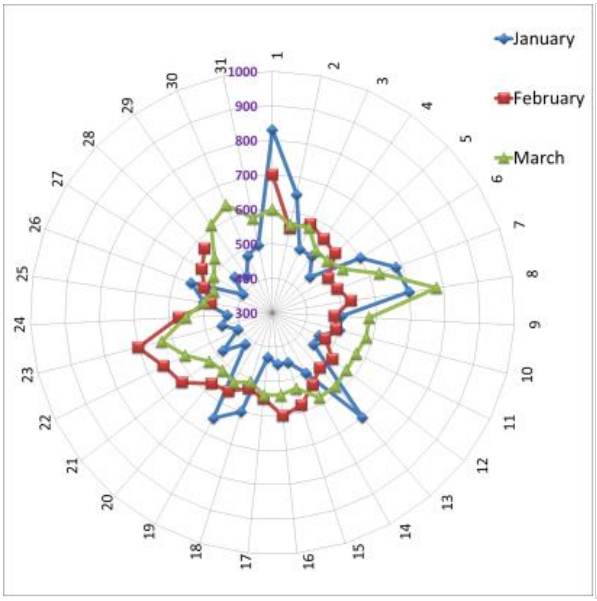


Figure 1. Distribution of orders by date in the first quarter of the year

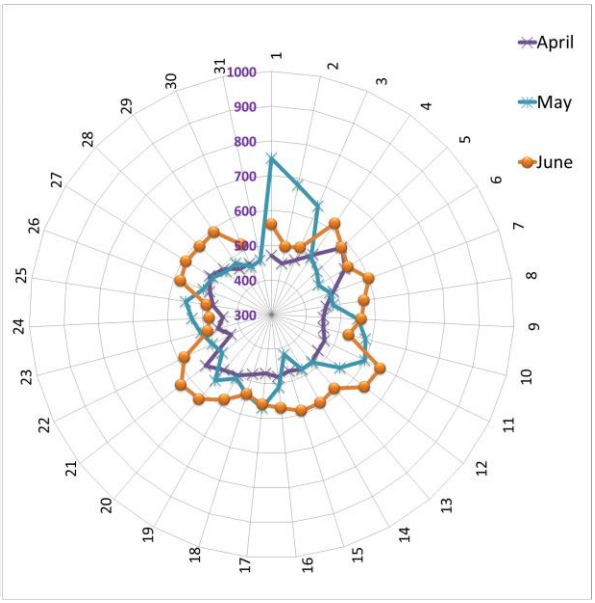


Figure 2. Distribution of orders by date in the second quarter of the year

Such results are useful for specialists in transport and sociologists.

The increase in the number of orders is noticeable in the autumn months, due to deteriorating weather conditions (for example, start and finish of September on Figure 3,) as well as the end of holidays and vacations (Figures 3, 4). The lowest number of trips is in July, due to annual leave and summer student vacation (Figure 3).

Figure 5 shows the analysis results of the average number of orders for taxi transportation for hours a day with a division of days on weekdays and weekends (for the majority of the population).

On weekdays there is a noticeable surge in the number of orders around 8:00 in the morning, due to the movement of population to work and study, and a gradual decline in the number of orders after 23:00 with a gradual growing up, that after 4:00.

On the weekend there is a surge in the morning, and it is moved to 10:00, there is a significant increase in the number of orders after 19:00 (start of the night shift) and then it decreases after 00:00, with a smooth increase at 3:00 and the hasty growth after 4:00. This behavior of the curve in orders

during the night (especially on weekends) explained mode of cultural and entertainment facilities work in the town (until 2:00 - 4:00).

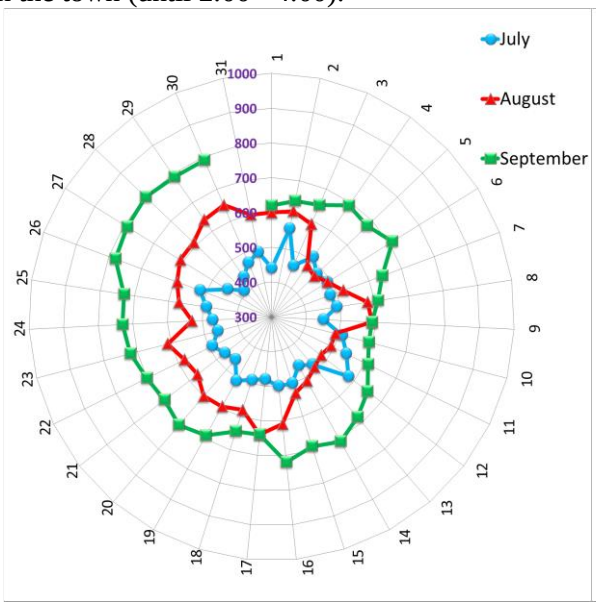


Figure 3. Distribution of orders by date in the third quarter of the year

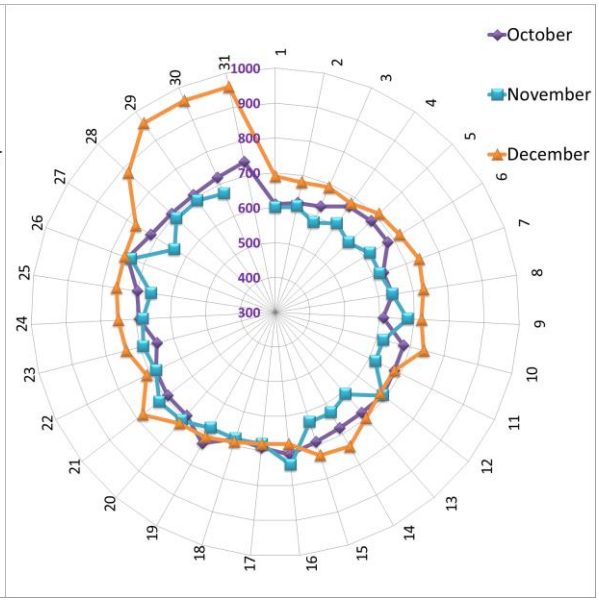


Figure 4. Distribution of orders by date in the fourth quarter of the year

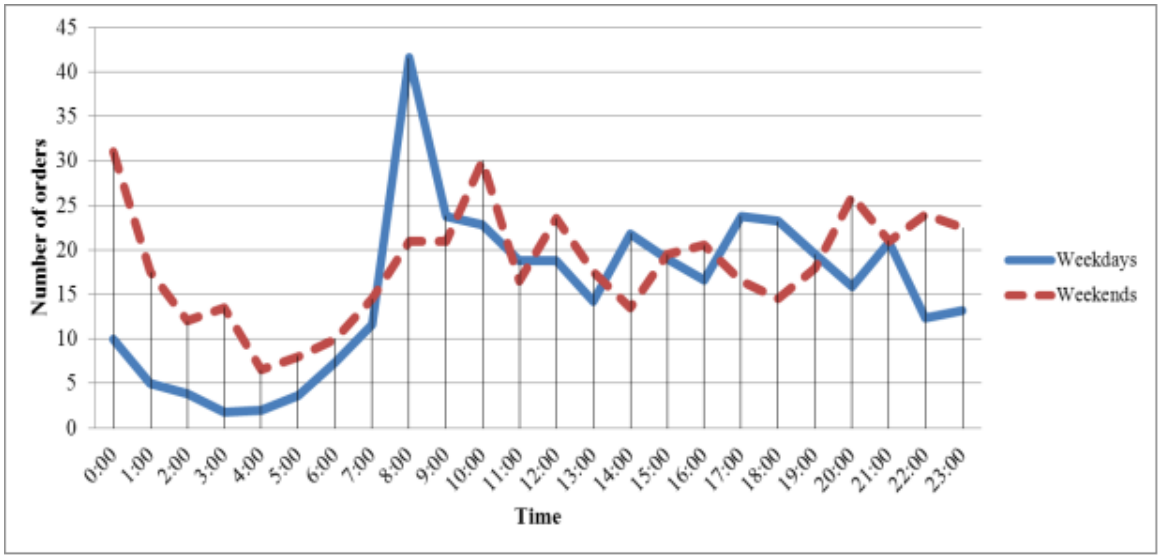


Figure 5. Distribution of orders for taxi transportation for every hour of a day (on average) on weekdays and weekends

Available studies [5] give a different character of changes in the for taxi transport demand for the hours of the day. They significantly differ from our data: on weekdays and weekends the maximum demand is for the period from 19:00 to 20:00, slightly lower demand is for the period from 11:00 to 12:00, at the weekend there is no increase in orders during the nighttime and etc. This is due to the fact that the analysis was carried out for sufficiently large cities that have a different way of life.

The data has been grouped for the weekdays and the time of the day. Thus, it is possible to obtain four data groups: weekdays-day, weekdays-night, weekends-day, weekends-night.

But this separation reduces the volume of each sample, which may adversely affect the choice of the taxi orders distribution law. We have checked whether it is possible to combine several groups of data. To do this, we have checked the hypothesis of equality of average collected in pairs of data samples [6].

In Figure 6 there is a diagram of the Box-Whisker graph representing all four data samples, as well as their quartiles, range and average values.

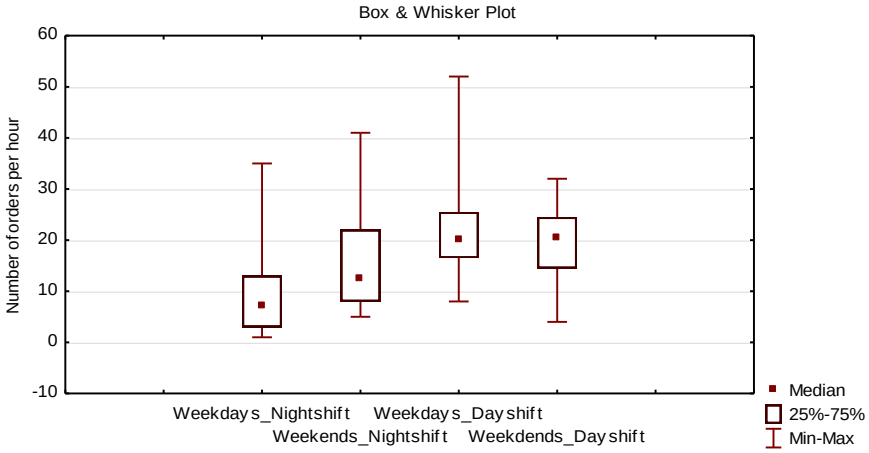


Figure 6. Box-Whisker diagram of orders distribution

For the comparison of the average one in the two samples, the Sign test and Wilcoxon test criteria are used.

On the basis of the application of these "weekends-night" and "weekends-day" selection criteria, we have united in one sample "weekends" and "weekdays -night" and "weekdays-day" samples have been handled separately.

We have determined the distribution law of taxi transportation orders moments with using Kolmogorov-Smirnov test and Pearson's chi-squared test (χ^2) [6].

The procedure for the distributions selecting showed that these random samplings are best described by Poisson distribution, the approximation accuracy is p = 0.35 with Kolmogorov-Smirnov criteria d = 0.15 and Pearson criteria χ^2 = 8.36 (Figure 7).

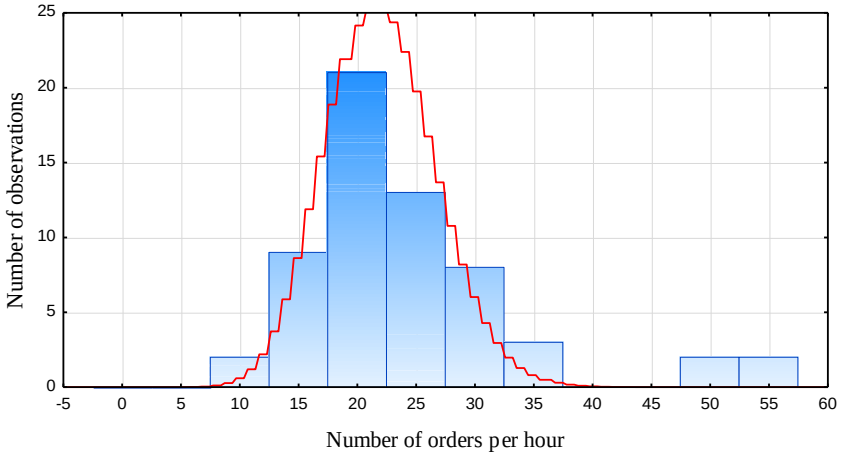


Figure 7. Poisson distribution for the "weekdays-day" sample

These have the following Poisson distribution law parameters: "weekdays-day" is λ=20.05; "weekdays-night" is λ=9.47; "weekends" is λ=17.63.

Formalization and modeling of the problem

There are different models developed for the taxicab problem [1, 7, 8, 9]. In our opinion to achieve the purpose of the article the queuing system (QS) apparatus is the best.

The system of taxi services has been observed as a queuing system with the expectation of an open unlimited application number in the system. According to Kendall's notation, it is the M/M/s type system [7, 8].

A mathematical model for calculating this QS type parameters is based on obtained Poisson distribution and it is given in sources [7, 8].

The parameters of the queuing system have been calculated according to the QS model [7, 8] and the results have been summarized in Table 1. The data has been represented in Table 1 in graphic form (Figures 8, 9).

Table 1. Taxi service parameters as a queuing system

Parameter QS	Weekdays-day			Weekdays-night				Weekends		
c, [pcs.]	8	10	12	4	5	6	7	8	10	12
λ, [1/h]	20.05	20.05	20.05	9.47	9.47	9.47	9.47	17.63	17.63	17.63
μ, [1/h	3	3	3	3	3	3	3	3	3	3
$\lambda/c\mu$	0.835	0.668	0.557	0.789	0.631	0.526	0.451	0.735	0.588	0.49
p_0	0.0009	0.0012	0.0012	0.0294	0.0391	0.0416	0.0423	0.0025	0.0028	0.0028
p_c	0.088	0.059	0.021	0.122	0.102	0.057	0.026	0.087	0.037	0.010
L_q, [pcs.]	2.73	0.36	0.06	2.16	0.47	0.13	0.04	0.91	0.13	0.02
L_s, [pcs.]	9.41	7.04	6.74	5.32	3.63	3.29	3.20	6.79	6.01	5.90
W_q, [h]	0.136	0.018	0.0029	0.228	0.050	0.014	0.004	0.052	0.007	0.001
W_s, [h]	0.469	0.351	0.336	0.561	0.383	0.347	0.337	0.385	0.341	0.334

Notations: λ – intensity of incoming orders for taxi transportation, [1/h]; μ – service intensity, [1/h]; n – the number of simultaneously being served and service waiting clients, [pcs.]; c – number of vehicles in the system, [pcs.]; $\lambda/c\mu$ – coefficient of the system loading; p_0 – probability of system downtime; p_c – probability of employment for all vehicles; L_q – number of customers in the queue, [pcs.]; L_s – number of clients in a system, [pcs.]; W_q – average waiting time in the queue, [h]; W_s – the average client residence time in the system (in standby mode and service), [h].

Summary

The scientific novelty of the presented work consists in the determination of:

- change in the number of orders for taxi transportation for months of the year, days of the week and hours of the day and the parameters of their distribution laws for the district center;
- the dependence of demand for taxi transportation on the weather conditions and the presence of holidays, student vacations and the season of annual leave;
- the parameters of the taxi transportation system as a queuing system for different periods of time in the district center.

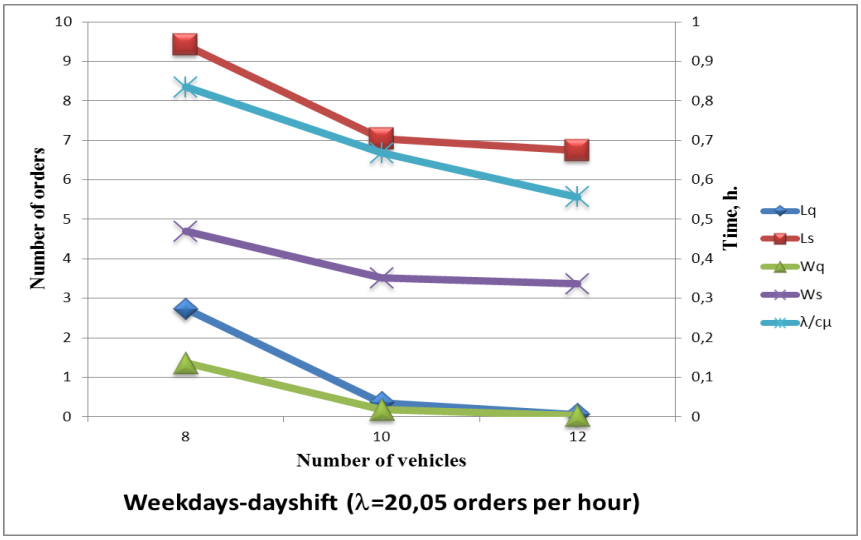


Figure 8. QS parameters for the "weekdays-day" period

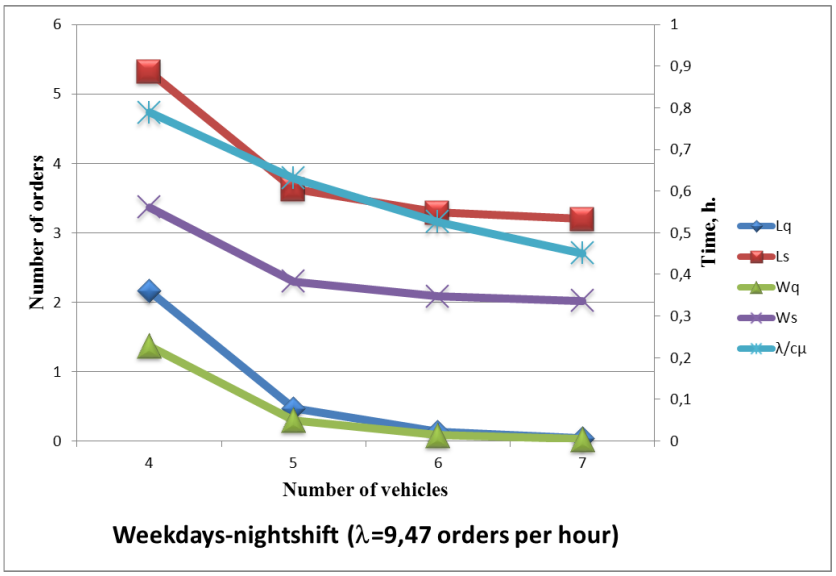


Figure 9. QS parameters for the "weekdays-night " period

The study results provide the following conclusions:

- for the "Troika" enterprise of the district center Zernograd on weekends around the clock and in the afternoon on weekdays there is need for only 10 cars, and a weekday night – 5 cars (that is less on the 2 and 3 pcs. respectively than currently used number of cars), with the system load factor is 0.6–0.7;
- there is possible to develop rational operation schedules for taxi vehicles and drivers in for months of the year, days of the week and hours of the day that provide the high efficiency of taxi cars during 24 hours timely population demand satisfaction.

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