QUEUE THEORY AND IMPROVING THE CUSTOMER SERVICE PROCESS IN THE CITY HALL – CASE STUDY

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Introduction/background: The objective of the article is to present possibilities of using queue theory at the City Hall to improve the service process. In recent years, the demand for high-quality customer service in an industrial city has increased, as it causes the applicant, and in the case of urban logistics – a resident, to become tied to their place of residence. This results in an increase in the number of residents, and thus leads to the development of the city and an increase in its resources (also financial).
Aim of the paper: The objective of the article is to present possibilities in City Hall offices of using queue theory to improve the service process.
Materials and methods: The article shows the application of mathematical methods in customer service in logistics.
Results and conclusions: Queuing systems have particular use in administration. Proper organisation of the work of an office or department enables fast and efficient service and customer satisfaction. The analysis of customer mass service systems is carried out in order to determine the optimal number of stations and to determine the general rules prevailing in the queue. When analysing the City Hall as a customer service system, it can be noticed that the usage of queuing theory to evaluate the system performance allows assessing the ability of the entity's logistics system to meet customer needs in terms of time, reliability and quality in accordance with the level of customer service.

Keywords: Queue theory in practice, customer satisfaction survey, optimization of customer service system.

1. Introduction

Customer service in logistics is among the latest aspects of logistics recently researched. The above term is increasingly important, not only for entrepreneurs or investors, but primarily for users. Moreover, in recent years, the individual resident has become the most important element of the city system, which makes efficient customer service more and more popular. From year to year, there are more indicators employed for examining customer satisfaction and compliance of the actual state with that expected by the consumer.

The article is an attempt to prove that, thanks to the application of mathematical models of queue theory, it is possible to calculate the optimal number of service points and the optimal service time with maximum mass customer satisfaction. The queue problem described in the article affects everyone, so resolving this issue is likely to save time and improve service quality. The thesis of the article was also formed: *The application of quantitative methods in City Hall offices in the process of servicing residents, increases customer satisfaction***.**

2. City logistics and city logistics system

City logistics currently serves as a tool that coordinates the unregulated system of cargo and people flow in the city, and is additionally customer-oriented – in this case, to a resident of a given urbanised region. Application of urban logistics procedures opens agglomerations to innovation and development, and introduces new IT systems supporting management (Szymczak, 2015). The individual is the most important element of the urban system, so the main objective of urban logistics according to B. Tundys is: ‘Providing the city user with the highest level of service at an acceptable cost of the flow of goods, information and people’. In addition, the activities of people managing urban logistics are focused on joining all the elements of the city's logistics system together, coordinating and controlling relations between them (Witkowski, 2015). The city's logistics system is a series of coordinated activities ensuring optimal flow within the system of goods, information and people. The city's logistics system and logistics processes occurring in it are closely related to meeting the diverse needs of users (mobility, manufacturing, learning, development, recreation, acquisition of goods, information) (Tundys, 2013).

3. The customer as a city resident

The modern customer is increasingly aware of their high position in the entire logistics chain. The Polish dictionary defines a customer as follows: ‘An interested party dealing with some matters in an office, department, using the services of an enterprise, facility, bank, etc. (...)’(Szymczak, 1978). The City Hall (in particular, the City Council Offices), is an institution in the city that deals with residents. The operation of this institution is financed from citizens' taxes, which is why a person who goes to the City Hall to sort a specific matter or acquire information should be treated as a customer who (due to paying taxes) purchased the service. More and more offices are taking on this strategy (Jórczak, 2015). It allows building good relations with the residents, and thus to develop the city and the society functioning in it.

I. Fechner defines customer service as ensuring the usability of space and time in the process of moving goods between the seller and the buyer.

It can be said that customer service logistics, as a process, consists of three basic parts (Fechner, 2007):

- Determination of the demand for a given service,
- data transformation and service implementation,
- assessment of the efficiency and effectiveness of service by comparing the actual state level with the declared.

Customer service in logistics raises the interest of both people related to marketing research and logistics. Customer service occupies a central position among logistics activities (Bendkowski et al., 2010) Due to the growing number of competitors on the market, customer service is increasingly important for the sale of a product or service, hence, we can say that customer service is complementary to marketing activities. Customer service in logistics can be described as a system of solutions that guarantee customer satisfaction. It is the ability to dynamically respond to customer expectations and requirements. Moreover, customer orientation allows long-term relationships (Walasek, 2014).' Thus, 'The customer service level (CSL, logistics customer service) is defined as the ability of an enterprise's logistics system to meet customer needs in terms of time, reliability, quality and convenience'.

4. Characteristics of customer mass service systems

Queue theory is based on probability theory. It examines the behaviour of systems and their basic parameters when queues begin to form. Queue theory is used in various fields of science. Its precursor is A.K. Erlang, a Danish mathematician who in his work examined the load on telephone exchanges. He published his first work in this field in 1909. Another scholar associated with queue theory is D.G. Kendall, who is considered the founder of mass theory (Oniszczuk, 1995). This theory is closely related to the issue of queuing systems and networks. The concept finds its use in modelling various service systems. Referring to the goal of city logistics, which is to provide the city user with a high level of service, the queue theory in the context of this system may have a positive impact on customer service. Important concepts in the case of mass service theory are (Filipowicz, 2008):

- arrival rate – average number of people arriving per unit of time,
- request intensity – average time between incoming requests,
- service rate – average number of people served in a given unit of time,
- traffic intensity parameter – arrival rate and service rate, which shows how many customers approached the service point and were correctly served per unit of time.

Two situations are distinguished (Filipowicz, 2008):

- when the arrival rate is less than the service rate; then the probability that the queue has a certain length per unit of time is constant,
- when the arrival rate is greater than the service rate; then the system is unstable and the probability of the queue lengthening over time increases.

Queuing systems have their particular application in administration. The proper organisation of work of each office or department enables quick and efficient service of the applicant and increases the efficiency of work and customer satisfaction (Filipowicz, 2008). The analysis of mass customer service systems is carried out in order to determine the optimal number of service points or to determine the principle of selecting tickets of those waiting in line for service. The objective of this analysis can be to determine the optimal average waiting time and to calculate the length of the queue. Due to the fact that the time of arrival of those waiting to enter the system and the exact time of service are not known, they are accepted as random variables. In queuing systems, it is important to properly select the number of servers for efficient and effective service. After service, applicants leave the system.

The creation of several queues that are characteristic of multi-channel and multi-phase mass service systems is allowed. These classes differ in the priority of service (priority service systems)'(Obretenow, 1989).

The theory of mass service also deals with the construction of mathematical models that can be used to manage any system.

The simplest model includes (Obretenow,1989):

- a source of requests, which is characterised by:
  - finite (when the source generates an exact number of tasks) and infinite dimensions (when new requests can come in an unlimited number to the system),
  - the time between individual requests being described using a random variable U with the cumulative distribution function $A(x) = P(\bar{u} \leq x)$ where $\bar{u}$ is the average value of time intervals between requests,
- a queue, described by maximum length and regulations,
- a request service point, characterised by the duration of handling one request,
- traffic intensity (Erlang constant) - the quotient of the average number of requests that flows into the system per unit of time to the average number of requests that can be handled per unit of time.

Kendall's notation

The queue system is described by 3 parameters (Smolarek, 2006):

1. Arrival time.
2. Service time.
3. Number of service points.

Queuing systems in Kandall's notation are described as follows:

parameter1/parameter2/parameter3

where:

Parameter 1

M = Poisson arrival time

D = Deterministic arrival time

Parameter 2

M = Poisson service time

G = General service time

D = Deterministic service time, this means that the service time must be set from above, e.g. at the production line or automatic car wash (Kotowski, 2009).

Parameter 3

Number of service points

Parameter 4 (does not always occur, in the infinite system this parameter is omitted)

Number of places in the system (including those at customer service points and in the queues).

Examples of queuing system description using the parameters put forward above are presented in Table 1.

Table 1.

Examples of system description using Kendall's notation

M/M/s	M/G/1	M/D/1
• Input stream with parameter λ • Exponential service with the μ parameter • Number of service points s • FIFO service discipline • Single queue • An infinite queue	• Poisson input stream with the λ parameter • Service time with any μ distribution and σ standard deviation • One service point	• The service time is deterministic, i.e. it has been agreed in advance. It is possible to switch from the M/G/1 system to the M/D/1 system assuming the standard deviation value σ = 0

Source: Kotowski R. Elementy Modelowania Matematycznego (Elements of Mathematical Modelling). Lecture 9. Department of Applied Computer Science. PJWSTK 2009.

The mathematical model of mass customer service systems includes the random variables and assumptions given in Table 2, and is also based on the theory of stochastic processes. Thanks to suitable mathematical formulas, the system user or observer can calculate queue-waiting time, probability of queue lengthening, etc. based on various variables. Usually two cases are considered (Kotowski, 2009):

- when the system heads towards a balanced state
- when the system is unstable.

Table 2.
Essential assumptions and random variables of mass service systems

Assumptions	Random variables
• probability distribution type of random variables, deterministic distribution, exponential distribution, Erlang distribution, any distribution, • dependence or independence of random variables - waiting time for requests and service time, • service discipline in force in the system, • it is assumed that R (number of service points) converges to infinity,	• time between subsequent requests entering the system, • request service time by one service point, • number of service points, • number of people waiting in the queue (finite, infinite queue),

Source: http://pja.mykhi.org/mgr/1sem/EMM/tronczyk/EMM_W_9.pdf.

Table 3.
Mathematical formulas used in queue theory

Description	Formula
The probability that there are no customers in the system, i.e. n = 0	$P(n=0)=\frac{1}{\sum_{i=0}^{r-1}\frac{p^i}{i!}+\frac{p^r}{(r-p)(r-1)!}}$
Average number of people waiting in queue	$Q=\frac{p^{r+1}P(n=0)}{(r-p)^2(r-1)!}$
The probability that the waiting time in the queue is longer than t_0	$P(t>t_0)=P(\mathrm{n}>r-1)\mathrm{e}^{\mu t_0(\mathrm{r}-\mathrm{p})}$
The probability that the customer will have to wait (under the condition that $n_o \geq r-1$)	$P(n>n_0)=\frac{r^{r-n_0}p^{n_0+1}P(n=0)}{(r-p)r!}$

Source: http://pja.mykhi.org/mgr/1sem/EMM/tronczyk/EMM_W_9.pdf.

It is important to first determine whether the queue is getting smaller, bigger or remaining unchanged. A favourable situation for the institution servicing the customer is that the work of the servicing person is not interrupted and that that institution is able to take full advantage of its human resources. The customer who wants to be served immediately looks at the queue problem from a different perspective. Knowing the arrival rate λ and the service rate, he/she can determine whether the queue has a certain length in each unit of time and is heading towards a balance or shrinks and then the inequality $\lambda < \mu$ occurs, or whether the system is unstable and then $\lambda \geq \mu$. In the second case, the service channel cannot make up for the lost time in which e.g. the service point was temporarily closed. Hence, by knowing the basic parameters of the queue, the institution can determine whether it needs to improve the work of a given service point or open a new one (Jędrzejczyk et al., 1997).

5. Queue theory in practice – case study

In one City Hall, an issue was identified which generated queues for service points responsible for issuing transportation documents. As a solution, an additional service point was considered. For the purpose of assessing the effectiveness of this proposal, traffic intensity was monitored and a customer satisfaction questionnaire was created and conducted on a group of 100 people. Among other issues, the following were checked:

- time between arrival of next customer,
- individual customer service time,
- waiting time in queue.

Observations took place at the following times: Monday 13:00-16:00, Tuesday 10:00-12:00, Wednesday 11:00-13:00, Thursday 9:00-11:00, Friday 12:00-14:00.

During the research period, 183 applicants visited the City Hall office. In Table 4, the results of observations carried out on Monday from 13:00 to 16:00 are presented. At that time, 51 people visited the city council office, but only 44 people decided to stay and wait in the queue (Głos, 2016).

Table 4.
The result of the observation carried out at the city council office on Monday

Day of the week	Number of open service points	Observation hours	
Monday	2	13:00-16:00	
Customer number	Arrival time (counted from the time the previous customer arrives until the next one arrives) [min]	Customer waiting time in queue [min]	Service time [min]
1	1	0	6
2	2	0	7.5
3	1	0.5	8
4	0.5	2.5	9
5	1	0.5	5.5
6	4.5	0	6.5
7	1	0	8
8	0.5	0	5
9	3	3.5	5
10	0	5	6
11	0.5	8	5
12	4.5	12.5	8.5
13	6	16	11
14	1	16.5	16
15	0.5	25.5	2.5
16	0.5	26.5	3
17	1	28.5	2.5
18	1	29.5	2.4
19	0.5	29.9	5.5
20	0.5	15	6.5
21	4	20.5	3.5
22	3	19.5	2.5
23	1	15	5
24	1	16	6.5
25	1	20.5	4.5
26	5.5	23	5.5
27	4.5	22	2.5
28	1	14.5	5.5

Cont. table 4.

29	0.5	14.5	3.5
30	1	0	3
31	0.5	0	5
32	1	3.5	4
33	1.5	6	7
34	1	10.5	5
35	1	13	5.5
36	1.5	16.5	6.5
37	1	20.5	4.5
38	0	22.5	8
39	0	29.5	7.5
40	2	37	3
41	1	38	4.5
42	1	39.5	3.5
43	0.5	41	1.5
44	1	41	1
TOTAL	**66**	**703.9**	**237.9**

Source: Own study based on the conducted observations.

Arrival rate on Monday from 13:00 to 16:00 is:

$$\lambda = \frac{44}{66} \approx 0.667 \tag{1}$$

Service rate:

$$\mu = \frac{44}{237.9} \approx 0.185 \tag{2}$$

Using the values of both parameters, the traffic intensity parameter was calculated while two service points are open, i.e. r=2:

$$p = \frac{\lambda}{2*\mu} = \frac{0.667}{2*0.184} \approx 1.8 \tag{3}$$

The above calculations show that $\lambda > r\mu$, which means the advantage of the arrival rate over the service rate. The p parameter value is also greater than 1, which suggests that the above system is unstable, i.e. the queue length is constantly increasing. Hence, achieving a state of balance is only possible if the time to service individual customers is reduced or a new service point is opened. The probability that there will be no queue in this system was calculated from the formula: P(n=0).

$$P(n=0) = \frac{1}{1+1.8+\frac{1.8^2}{(2-1.8)(2-1)!}} = \frac{1}{2.8+\frac{3.24}{0.2}} = \frac{1}{20.05} \approx 5.2\% \tag{4}$$

It was next calculated what the probability was that the customer would not have to wait in a queue when coming to the City Hall, assuming that only two service points are open.

$$P(n>0) = \frac{2^{2-0}1.8^{0+1}5.2}{(2-1.8)2!} = \frac{4*1.8*5.2}{0.2*2} \approx \frac{37.9}{0.4} \approx 94.8\% \tag{5}$$

This means that there is as much as 94.8% probability of event A occurring, which means that the customer entering the system will have to wait in the queue.

Subsequently, it was ascertained as to what the probability was that there would be more than two people in a queue when coming to the City Hall on a given day, and that the waiting time would be more than 3 minutes.

Probability of more than 2 people in the queue:

$$p(n > 2) = \frac{2^{2-2} * (1.8)^3 * 5.2\%}{0.2 * 2!} \approx 76.98\% \tag{6}$$

The probability that the waiting time in the queue will be over 3 minutes, assuming that e is 2.7182:

$$p(t > 3) = p(n > r - 1)e^{-\mu t_0(r-p)} = p(n > 1)e^{-0.185*3*(2-1.8)} \approx 91\% \tag{7}$$

Average number of customers waiting in the queue:

$$Q = \frac{p^{r+1}P(n=0)}{(r-p)^2(r-1)!} = \frac{1.8^3 * 0.052}{(2-1.8)^2 * 1!} \approx 7.6 \tag{8}$$

In order to check the probability of waiting time over 5 minutes, 7 minutes, 9 minutes, 12 minutes and 15 minutes, subsequent calculations were made, the results of which are presented in Table 5.

Table 5.
Probability of waiting time

Probability of waiting time	Calculation result
Over 5 minutes	71%
Over 7 minutes	66%
Over 9 minutes	61%
Over 12 minutes	55%
Over 15 minutes	49%
Over 30 minutes	29%

Source: Own study based on the conducted research.

The results of calculations carried out in a manner analogous to Monday for the remaining days are presented in Table 6.

Table 6.
Test results from subsequent days of the week

Day of the week	Tuesday	Wednesday	Thursday	Friday
Observation hours	10:00-12:00	11:00-13:00	9:00-11:00	12:00-14:00
Number of open service points	2	2	2	2
Number of customers served	29	34	37	39
Number of people abstaining from the service	5	7	2	5
Parameter name	**Calculation result**			
	Tuesday	**Wednesday**	**Thursday**	**Friday**
Arrival rate	0.70 persons per minute	0.64 persons per minute	0.58 persons per minute	0.64 persons per minute
Service rate	0.21 persons per minute	0.24 persons per minute	0.17 persons per minute	0.24 persons per minute
Traffic intensity parameter	1.67	1.34	1.37	1.34
The probability that there will be no queue	8.89%	19.81%	9.14%	19.81%

Cont. table 6.

The probability of more than 2 people in the queue	63.79%	35.93%	62.97%	35.93%
The probability that the waiting time will be over 3 minutes	86.16%	35.5%	88.15%	62.1%
Average number of people waiting in queue	4 people	1 person	4 people	1 person
System Type	Unstable system	Unstable system	Unstable system	Unstable system
The probability of a waiting time over 5 minutes	54.2%	24.3%	56.5%	54.2%
The probability of a waiting time over 7 minutes	47.3%	17.7%	50.3%	41.3%
The probability of a waiting time over 9 minutes	41.3%	12.9%	44.7%	40.3%
The probability of a waiting time over 12 minutes	33.6%	8%	37.6%	33.6%
The probability of a waiting time over 15 minutes	27.4%	5%	31.5%	25.4%
The probability of a waiting time over 30 minutes	9.9%	0.5%	13.1%	9.9%

Source: Own study based on the conducted research.

The research shows that the queue system was not stable on any day of the week, which means that the probability of the queue occurring continued to increase. The lowest traffic intensity parameter occurred on Wednesday between 11:00-13:00 and on Friday between 12:00-14:00 and was 1.4. The average probability that there will be no queue is around 15%.

The next stage of the research was to conduct a survey addressed to adult residents of the studied city, containing questions about service time, waiting time in queues, quality of the service and information flow. 100 respondents: 66 women and 34 men took part in the questionnaire sent via e-mail. The conducted research shows that the average waiting time in a queue, according to clients of the City Hall, is 2-10 minutes (47% of all respondents), 11-15 minutes (44% of all respondents), over 15 minutes (8% of all respondents), 0-1 minutes (1% of all respondents). In addition, 73% of all respondents believe that the waiting time in a queue should be shorter, as it significantly affects the quality of the service. Thus, the waiting time in the queue is strongly correlated with the speed of service of individual people. Most of the respondents (79%) believe that the service should be much faster. The remaining respondents have no objections to the time of service. 78% of all respondents confirmed that it is necessary to introduce an electronic queuing system that would shorten the waiting time for service or force opening of one additional customer service station.

Another question was about the impact of the speed of service and waiting time in queue on customer satisfaction. The answers to this question are presented in figure 1.

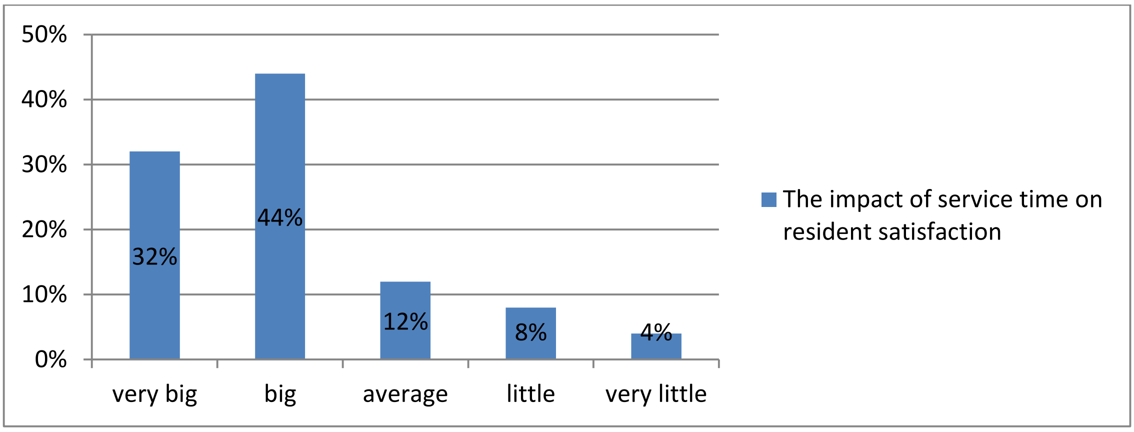

Figure 1. The impact of service time on resident satisfaction. Source: Own study based on the conducted research.

Figure 1 shows that service time is a very important factor that affects customer satisfaction. Overall, 76% of all respondents feel that is has a big or very big impact, and the studies have confirmed that the waiting time in the queue at the city council office is very long, which significantly affects customer satisfaction.

The survey ended with an open question soliciting changes that might improve the logistics of mass customer service. Examples of enhancements provided by respondents include:

- "Possibility to start the procedure via the Internet. In this case, I would come to the office to finalize the case, without the need of several visits."
- "Introduction of an electronic queue system and opening more service stations in case of increase of queues."
- "Better description of each service station to avoid waiting in a wrong queue."
- "Increase number of customer service stations".

In order to check what actions should be taken to improve the mass customer service process, simulations were carried out, consisting in calculating the arrival rate, service rate, probability of queue occurrence, average number of people waiting in the queue and type of arrangement for two systems:

- system 1, in which three service points are open,
- system 2, in which the time of serving a single customer amounts to a maximum of 5 minutes.

System 1 simulation

In the initial phase, an additional service point is opened, i.e. r = 3. The number of customers, service time and time from arrival to service does not change. The simulation results are presented in Table 7.

Table 7.
System simulation with an additional service point

Parameter name	Calculation result
Arrival rate	0.67 persons per minute
Service rate	0.18 persons per minute
Traffic intensity parameter	1.8
The probability that there will be no queue	28%
Average number of people waiting in queue	1 person
System Type	Stable system

Source: Own study based on the conducted research.

System 2 simulation

It has been assumed that the introduced service time does not exceed 5 minutes. The number of customers, the number of service points and the time between the arrival of subsequent customers does not change. The simulation results are presented in Table 8.

Table 8.
Service system with fixed service time

Parameter name	Calculation result
Arrival rate	0.67 persons per minute
Service rate	0.31 persons per minute
Traffic intensity parameter	1.06
The probability that there will be no queue	29.10%
Average number of people waiting in queue	0-1 person
System Type	Unstable system

Source: Own study based on the conducted research.

Comparison of the proposed systems with the current state

In Table 9, the following were compared: current state, predicted state after starting system 1 and predicted state after starting system 2. All systems are based on data from Monday.

Table 9.
Comparison of the current state and predicted states

Parameter	Current state	System 1	System 2
Arrival rate	0.67	0.67	0.67
Service rate	0.18	0.18	0.31
Traffic intensity parameter	1.8	1.8	1.09
The probability that there will be no queue	5.2%	27.65%	29.1%
Average number of people waiting in the queue	7.6	1.02	0.47

Source: Own study based on the conducted research.

Based on the above results, it can be seen that both the introduction of an additional service point and the reduction of service time for individual customers to a maximum of 5 minutes will increase the performance of the system, reduce the probability of queues, and reduce the number of people waiting in the queue. The rate of arrival of customers has not changed in any of the systems, while the service rate has only changed in system 2, which assumes a change in customer service time.

The results of statistical manipulation indicate that opening another service point will allow faster customer service, and that shorter waiting time in the queue will improve customer satisfaction. The above improvements will increase the probability that the customer will not have to wait by more than 22% (from 5.2% to 27.65%). The average number of people waiting in the queue will also decrease from seven to one.

6. Summary

Queuing systems have particular use in administration. Proper organisation of the work of an office or department enables fast and efficient service and customer satisfaction. The analysis of customer mass service systems is carried out in order to determine the optimal number of stations and to ascertain the general rules prevailing in the queue. When analysing the City Hall as a customer service system, it can be noticed that the usage of queuing theory to evaluate the system performance allows assessing the ability of the entity's logistics system to meet customer needs in terms of time, reliability and quality in accordance with the level of customer service.

Customer service is defined in the literature as a system of solutions ensuring such relations between the time of placing the order and the time in which the product is delivered to the customer so as to fully satisfy them and maintain this satisfaction as long as possible. Therefore, queue theory can help shorten the waiting time and customer service, which according to the research, will significantly affect the satisfaction of residents. The conducted simulations showed that the introduction of a new service point or reduction of customer service time to 5 minutes, would improve the logistic process of customer mass service, and increase the customer's satisfaction. The usage of quantitative methods in the process of servicing residents in the City Hall helps to increase customer satisfaction.

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