STATISTICAL EVALUATION OF EMERGENCY SERVICE DEMAND IN ELECTRIC POWER DISTRIBUTION UTILITIES

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KEYWORDS

Electric power distribution, queueing theory, operations research, performance evaluation, service systems.

ABSTRACT

Waiting time in queues constitutes a common problem in customer service systems, where delay is perceived as cost by customers enrolled in the process. In electrical energy maintenance services, this delay is attenuated by the entry of emergency repair orders. This paper aims to evaluate the emergency service demand through a queuing model. For this purpose, emergency order records were analyzed and, after adequate statistical treatment for these data due to their inherent variability, it was possible to calculate some performance indexes. From these results, it was possible to analyze how the variation of some key parameters impacts the system, in order to provide information for the decision making regarding the service system

INTRODUCTION

The performance of a service system deserves a similar emphasis to that of strategic areas within companies, with the damages and implications resulting from low performance being the main causes for such an emphasis (Fitzsimmons and Fitzsimmons, 2010). (Toor, 2008) reports the importance of the existence of a service level agreement, which includes not only the level of service promised, but corrective actions and penalties if this is below the established standard. In this same direction, (Wu, Lee and Cao 2009) highlight a practice used in public services, which consists in the elaboration of regulations for times of interruption of supply of a certain service, in order to ensure the minimization of the time in which the service leaves to be borrowed.

According to (Fitzsimmons and Fitzsimmons 2010), the waiting time to attend a given service is seen as cost by the individuals who are participating in the process. The authors point out that this waiting cost is something that is rarely explained in studies and analyzes, but the experience of being in a certain queue for a service must be the object of attention and observed by the service providers under the physical, behavioral and economic aspects. According to (Mital 2010), similar to the affirmation "zero defects" diffused in the industrial field, in the conjuncture of services the principle of "zero failures" must be followed, since the dissatisfaction of a certain client can go beyond the expected time for the service, arriving the withdrawal and subsequent change of service provider due to the poor performance of the service system, often materialized in the simple mismatch of expectations with the desired levels of service.

The evaluation and proposition of improvements within the field of services and operations, more precisely, in their service systems, are carried out by some works through the use of techniques and concepts traced in queuing theory. As examples, (Yankovic and Green 2011), (Chadha, Singh and Kalra 2012) and (Xu et al. 2014) work such concepts in their researches aimed at optimizing the performance of the service systems. In the context of the electricity distribution sector, the service rendering systems present, according to (ANEEL 2016), attributes such as perceived quality, satisfaction and reliability, turning around 70%, while reliability presents 48.08% as final index, which assumes that the sector as a whole suffers low confidence of its clients.

This paper deals with the development of a statistical analysis on the admission of emergency orders observed from a history series in order to enable a preliminary evaluation of a service delivery system in the electricity distribution sector. In the following section, the existing theoretical basis for the development of the study is presented. The third section shows the methods used to carry out the study and the results obtained from what was drawn. Finally, the fourth and last section contains the conclusions of this study and its main contributions, finalizing the work presenting suggestions for future work.

THEORETICAL REFERENCE

According to (Fitzsimmons and Fitzsimmons 2010), a queuing system corresponds to the waiting of clients who lack one or more services of a certain server (s). The authors comment on the fact that a queue does not necessarily have to be materialized in the form of a line and with people queuing; for example, queues can also be considered as individuals placed on standby by a certain telephone service or people waiting for medical care in an emergency care system.

Applications involving the study of queues may be of different natures. (Mayhew and Smith 2008) present in their work an application of the queuing study to evaluate a government policy, which establishes as goal a maximum limit of 4 hours of service time for 98% of emergency cases that arrive at public hospitals in the city of London, England. The authors demonstrate how the problem can be treated as a queuing case and show that,

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in the way the process was designed, it is not possible to reach the established time goal.

Another example of application of the queuing study is demonstrated in the work of (Zapata et al. 2010), where the authors present a model for modeling and optimization of repair processes in distribution units. The model, which can be summarized according to Figure 1, follows three major steps in its methodology: (i) adjusting a sample of failure events and service times data to probability distributions; (ii) simulation by Monte Carlo method from the probability distributions adjusted for failures and service times; and (iii) calculation and analysis of maintenance management indicators.

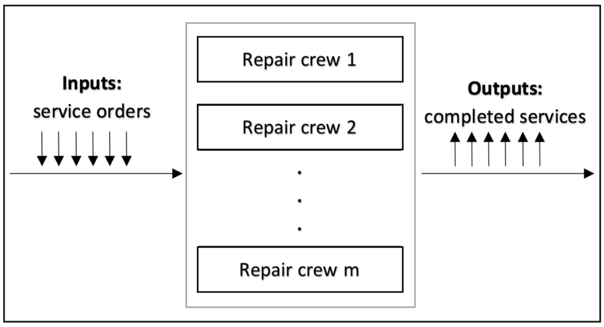

Figure 1: Queue model for the service system considered.

The concept of queuing theory materializes through the construction of models that are able to capture the behavior of the phenomenon in question and translate it into performance indicators. (Taha 2002) presents in his work several models that have application according to the type of queue one wants to study, highlighting the importance of the understanding behind the existing theory on the subject. (Hillier and Lieberman 2014) objectively point to queue models capable of capturing the behavior of the phenomenon and quantifying in the form of performance indicators the same. Within the models brought by the authors and aiming at the current situation in this study, the model of birth and pure death stands out, which is of direct application to the present case.

Assumptions for queuing models and statistical data processing

According to (Mital 2010), a queuing system basically consists of a standard of arrival of those who need a certain type of service, as well as a server standard, queue discipline, system capacity, number of channels services and service stages numbers. (Mital 2010) comments that for the construction of a queuing model capable of understanding the interaction between the elements and generating performance metrics about a system, some assumptions are necessary for such a model to be valid. These hypotheses are as follows:

- Only single orders arrive at the system and there are no mass arrivals;
- The lengths between the arrivals intervals are independent;
- The lengths between the arrivals intervals are identically distributed by a continuous density function;
- The times between arrivals and service times follow an exponential distribution, therefore, the arrival rate and the service rate follow a Poisson distribution;
- The discipline of the queue corresponds to the way customer service is given over time, for example, first-come, first-served (FIFO).

Another determining factor in the construction of queue models is the understanding of the type of data that is being worked on. A previous statistical analysis of the elements available for the study constitutes an important step, which is commonly performed in works with this approach. It is possible to observe such treatment in the work of (Cheevarunothai, Mooney and Wang 2007), in which the authors conduct an investigation of the data through basic descriptive statistics such as median and standard deviation, to then deepen the study through row theory.

(Zavanella et al. 2015) also highlight the relevance of statistical treatment of data prior to the study of queues per se. According to (Zavanella et al. 2015), the evaluation of the probability distribution of service times and the arrival rate are one of the premises for elaboration of the model, however, in cases where there is great variability it is necessary to evaluate how much such oscillation can impact on results. If it is necessary, it is fundamental that different unstable information that does not demonstrate a behavior pattern is considered and treated differently, and the disposal of such information is plausible in some situations.

STATISTICAL PROCEDURE DEVELOPED

The context of this study covers the particularities and constraints that exist in the service rendering process of an electric energy distribution company. It should be noted the complexity of the type of operation carried out by companies in this branch, and the existence of such complexity is attributed to the great variability observed in the entrance of scheduled and emergency services. These services, on the other hand, are processed by teams and need to be balanced with the company's processing capacity so that there is no idle resources or the maximum outdated processing capacity and a likely decrease in the level of service.

An alternative focus may lay on a context where different service levels could be associated with different customers. In that case, a direct correlation between service level and priority may be used to influence the order in which customers are attended, i.e.: customers with high service level will have high priorities, while customers with low service level will have low priorities. A simple way to do this ponderation would be, for example, use multipliers of type 1 (low priority) and 1,5 (high priority), which would result in a privileged service for the customers with higher levels of service.

The steps followed in this research aiming at the traced objective can be summarized as follows:

(i) Adaptation of the matrix formed by all information and data of the emergency orders: calculation of the standard deviations of the service times, per hour, and discard of the values which exceed ± 2 standard deviations, since these values represent possible abnormal variations of the service time, which compromise the modelling of the behaviour of the series;
(ii) From the new matrix formed, elaboration of two data series: accumulated time per hour and accumulated time per hour and day of the week;
(iii) Calculation of the mean and standard deviation of each accumulated series, as well as the Coefficient of Variation (CV) of these series, which corresponds to the division of the standard deviation by the mean;
(iv) Adjustment of probability distribution to lower CV series;
(v) Calculation of performance indexes of the row model.

Steps (i), (ii) and (iii) encompass the statistical examination of the data, while steps (iv) and (v) are part of the queuing model construction process. For the construction of such a model, the performance metrics for average service time, average exit rate and average arrival rate were calculated. Based on these indicators, it was possible to estimate other measures of relevance to the system capable of assisting in decision making regarding its operation.

SIMULATION RESULTS

This work includes the study of an electrical power distribution utility that serves a region corresponding to 99,000 km², serving 118 cities, approximately 1,300,000 customers and with an average of 500,000 services generated annually.

The data used to perform this research constitute the records of emergency orders from July 1, 2014 to July 31, 2015. Stratified by time of day (0 to 23), these records contain data of 392 days which, multiplied by the number of hours, result in 9,408 lines. It is worth mentioning the great variability existing in the data inherent to its emergent nature. Specifically, the service time attached to each hour of the day, which is usually composed of more than one order, presents great variation in the course of any day analyzed.

In this way, it is wrong to investigate the behavior of the emergency orders in a global way, considering as satisfied the hypothesis that such orders have similar behavior in their entirety. Thus, a statistical evaluation is necessary in order to give adequate treatment to the data and, in this way, to guarantee the infallibility of the solution presented later. This treatment of data due to instability composes some of the steps of the method used in this research.

Table 1 shows the header of the matrix formed by the emergency order records provided by the company studied, together with the possible values associated with each parameter. In addition, for purposes of understanding the treated matrix, there are some hypothetical lines of data disposition in the matrix until the last hour of the last day recorded in the matrix. Following what was described as the first stage of the methodology for this research, the first procedure consisted in the calculation of the standard deviation of the hours of service per hour.

Table 1: Matrix records of emergency orders

Year	**Month**	**Day**	**Day of the week**	**Hour**	**Service Time (hours)**	**# of requests**
2014 – 2015	1..12	1..31	1..7	0..23	Variable	Variable
2014	7	1	3	0	0.14	2
2014	7	1	3	1	0.20	3
2014	7	1	3	2	1.5	1
. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
2015	7	31	6	23	3.2	7

After this calculation, values that exceeded the lower or upper limits were discarded. Therefore, the new matrix remained with the same aspect presented in Table 1, but now contains 8,938 lines. Such a reduction relates to the lines containing service times exceeding the standard deviation limits and, therefore, have been removed entirely from the matrix.

After the preliminary analysis of the standard deviations, it was possible to observe that the variation of the service times occurs, specifically, under the parameters of day of the week and time of day. Thus, in order to compose the data to enable the calculation of queue performance indices, two data series were elaborated, corresponding to: (a) cumulative service time per hour and (b) accumulated service time per hour and by day of the week. In other words, in (a) we have the sum of all service times of the 392 days recorded for, for example, hour 0, followed by hour 1, hour 2, and so on. In (b), we have the same sum described in (a), but segregating the sum of the time by the 7 days of the week. Table 2 and and Table 3 provide the service time values corresponding to the series discussed.

For both series, the procedure of calculation of mean and standard deviation was repeated. With the upper and lower limits set at ± 2 standard deviations, the corresponding values of the series were plotted in graphs that can be visualized in Appendix A. It is observed the great similarity between the graphs, being possible to delineate a certain behavior of the times of service throughout the hours of each day.

In (a), a certain stability is observed from hour 0 to hour 8. From time 9, the series gains a variability behavior, which remains approximately until hour 19. From this time on, the time of service decreases, closing hour 23 with a value similar to the values presented in the stable interval between hour 0 and hour 8. This behavior is also noticed when we look at the 7 graphs derived from series (b).

Table 2: Series (a): accumulated service time (hours).

Hour	Accumulated service time (hours)
0	311,30
1	305,94
2	307,60
3	310,74
4	326,53
5	312,81
6	357,27
7	404,79
8	849,69
9	937,03
10	1020,34
11	865,62
12	741,12
13	1142,79
14	836,20
15	875,30
16	885,58
17	794,01
18	878,10
19	760,45
20	638,68
21	506,65
22	417,17
23	317,62

In (b), the stability between hours 0 and 8 is repeated, as well as the decrease and resumption of stability after hour 19. However, the points detected outside the upper control limit in the charts of days 4, 6 and 7, corresponding respectively to Wednesday, Friday and Saturday. In the three graphs, the point that is outside the upper limit is the point that corresponds to hour 13; in the other graphs of the days of the week, the points closest to the upper limit are the hours 9 (day of week 1 - Sunday), 13 (day of week 2- Monday) and 13 (day of week 5 - Thursday).

The last stage of the statistical treatment concerns the calculation of the series CV. For the purposes of analysis, the series (a), which includes the cumulative time of service per hour, was not considered in the CV calculation because, as already noted, its result is shown in a fractional way in the series (b).

Table 4 presents CV values per day for series (b), considering green squares for CV≤40%, yellow squares for 40%<CV<60% and red squares for CV≥60%. It is worth noting that there are only 4 CV values below 40%, 100 values are between 40% and 60% and 64 are above 60%. This represents that 2.38% of the values are in an acceptable range of variability (less than 40%), the rest being in doubt as to the stability and, consequently, the generalization of their results.

Table 3: Series (b): accrued time of service per hour and day of the week

Hour	Day of the week						
	1	2	3	4	5	6	7
0	40.57	49.13	49.81	41.82	48.41	42.26	39.30
1	41.99	45.81	46.38	43.22	44.94	41.74	41.87
2	38.53	52.17	47.26	41.09	47.50	42.25	38.80
3	43.14	46.33	46.72	40.60	48.91	44.21	40.83
4	43.25	49.94	48.17	45.67	48.20	49.70	41.60
5	44.20	45.83	49.02	40.78	45.74	45.11	42.13
6	41.95	54.08	48.12	57.78	49.29	61.21	44.84
7	56.09	57.16	58.53	59.64	57.33	67.25	48.80
8	95.41	122.62	137.93	127.93	134.09	117.65	114.06
9	109.46	140.23	151.12	140.11	142.91	135.67	117.53
10	100.46	146.67	170.11	169.96	163.56	159.17	110.41
11	99.49	125.70	129.56	135.11	128.05	138.23	109.49
12	81.04	98.84	112.03	124.25	114.86	113.14	96.95
13	78.83	161.10	164.27	199.42	184.98	201.13	153.05
14	80.97	130.19	111.96	143.66	119.00	140.34	110.07
15	75.35	141.54	140.97	138.03	137.12	139.27	103.03
16	74.71	142.27	143.03	130.05	138.87	139.44	117.22
17	81.87	122.69	129.58	123.10	130.06	117.05	89.65
18	80.23	132.13	137.24	138.36	144.21	138.30	107.61
19	94.06	115.84	104.28	120.43	117.65	108.70	99.50
20	66.90	105.22	98.36	107.45	96.77	90.51	73.46
21	63.62	70.84	66.11	80.80	88.49	78.50	58.30
22	51.87	62.17	65.58	61.20	60.85	64.91	50.59
23	42.27	42.59	46.36	47.51	51.35	46.24	41.30

Once the values of lower CV within series (b) were detected, the study of performance indicators was limited to these values only for these four new subsets. These subsections correspond to the sum of the individual values of service times for: all hours 9 on all days of week 2, all hours 9 on all days of week 4, all hours 11 on all days of week 4 and all hours 15 on every day of week 2. Figure 2, Figure 3, Figure 4 and Figure 5 present the histograms of the individual service times of subsections, showing that in the four cases we have a strong approximation of the exponential distribution for subsections.

By analyzing the individual time-of-service values recorded per hour, it is possible to notice that each service time registered is linked to a number of occurrences also recorded. Thus, it is possible to estimate the performance measures of average service time queues, average order arrival rate and average order exit rate. Table 5 presents these indicators for the four subseries.

Note that in all subseries the average order entry rate is higher than the average exit rate. It is also possible to notice that the greater the difference between the rates, the longer the service time is. Therefore, a possible measure to improve system performance would be to include more teams at these times these days of the week, or some other action that would be able to meet the demand for order entry, shortening service time.

Table 4: CV values for series (b), in percentages.

	Day of the Week						
hour	1	2	3	4	5	6	7
0	59.25	65.90	61.30	64.03	57.87	67.04	59.70
1	57.87	63.40	58.81	66.77	48.30	67.65	56.97
2	55.63	67.62	61.29	62.81	59.14	67.05	60.33
3	64.27	61.65	58.96	63.57	53.59	67.19	59.19
4	66.66	70.58	60.21	71.11	60.31	77.35	66.39
5	63.75	65.35	61.16	67.15	58.63	65.26	59.14
6	60.40	71.43	63.16	70.77	61.30	70.99	60.80
7	66.76	68.56	69.56	68.98	62.07	64.19	55.85
8	64.34	50.88	53.27	46.18	58.77	50.51	52.81
9	70.43	39.92	42.65	34.15	50.29	52.23	53.37
10	64.59	54.14	45.53	42.92	46.29	48.82	53.16
11	57.29	48.80	45.66	39.61	53.09	51.28	48.90
12	64.96	50.75	56.09	56.11	51.09	57.15	66.01
13	71.26	44.66	56.81	45.34	55.47	47.48	53.19
14	74.74	43.22	51.13	41.15	63.28	42.48	63.75
15	79.28	39.20	51.02	52.82	45.34	42.42	50.10
16	59.70	48.10	53.36	48.15	46.11	49.72	61.47
17	83.51	44.85	40.89	50.44	48.43	49.78	54.85
18	66.56	43.84	46.61	43.74	41.80	49.63	56.20
19	58.34	51.20	50.63	46.62	47.14	53.08	64.94
20	58.41	53.36	58.17	51.81	50.60	55.13	58.11
21	61.64	57.08	57.81	67.38	57.72	69.78	79.71
22	62.63	54.73	51.90	59.92	59.78	56.62	68.84
23	55.87	54.47	61.49	59.72	49.95	66.70	63.55

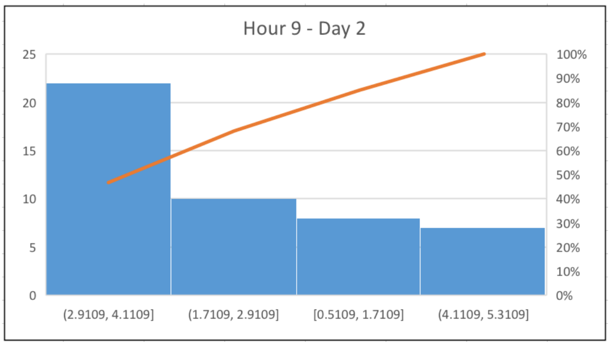

Figure 2: Histogram of the individual service times of the subset corresponding to time 9 and day 2.

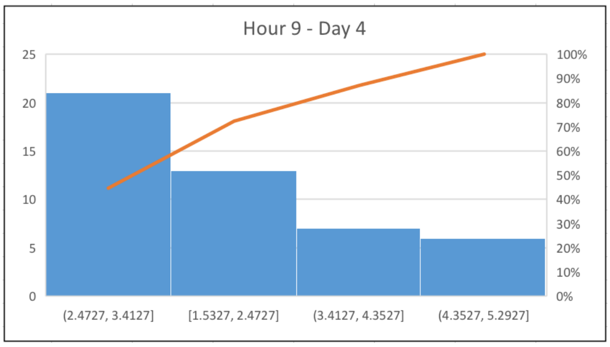

Figure 3: Histogram of the individual service times of the subset corresponding to time 9 and day 4.

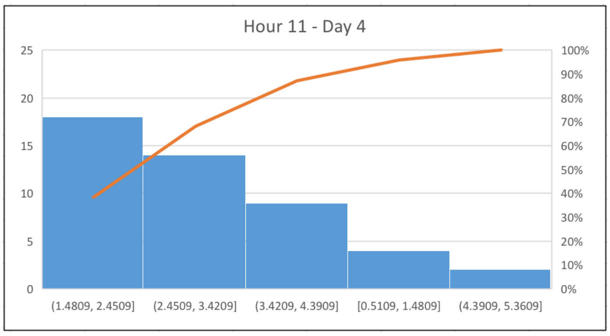

Figure 4: Histogram of the individual service times of the subset corresponding to time 11 and day 4.

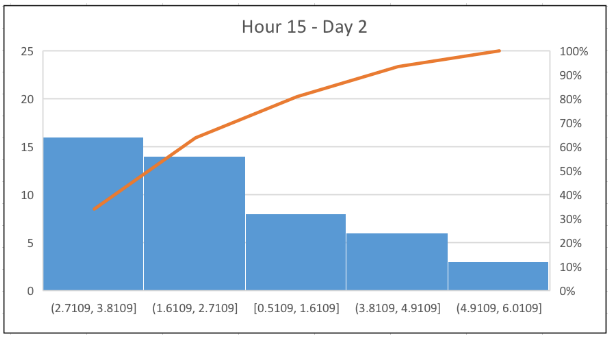

Figure 5: Histogram of the individual service times of the subset corresponding to time 15 and day 2.

Table 5: Performance indicator.

Indicator	Hour of day - Day of the week			
	9 – 2	9 – 4	11 – 4	15 - 2
Average service time (hours)	2.9836	2.9046	2.5807	2.9028
Average output rate (orders/hour)	0.3352	0.3443	0.3875	0.3445
Average input rate (orders/hour)	5.4255	5.4082	4.6981	5.1429

FINAL REMARKS

The performance of service systems is intertwined with the strategic relevance that such performance receives from organizations. Waiting time in queues is one of the consequences of the poor management of such systems, being seen as cost by some customers, which opens the door for possible service withdrawals or complaints regarding service delays and consequently waiting too long. Some authors defend certain strategies to avoid harm to the consumer by the inefficiency of the system, causing, in some cases, fines or penalties for the service providers.

In this sense, one of the found and diffused ways to study and control this phenomenon is demonstrated in queuing theory. The use of techniques and tools to capture the behavior of different types of queues compose an important measure, which can be seen in a strategic way by companies that are faced with this type of situation. In the electricity distribution sector, the queuing case is presented in the form of scheduling and emergency service orders, which form a kind of non-tangible queue, but which can be studied and analyzed by means presented in queue theory.

This work aimed at evaluating the performance of a service delivery system in the electricity distribution sector through the study of queues. From an initial statistical treatment of the data, due to the great variability inherent to this type of data, it was possible to arrive at the calculation of indexes that mirror the performance of the system as a whole. The final evaluation is that the system studied has a performance that needs improvements that aim to fully meet the demand for the entry of work orders, so that we can work on reducing the total time of service.

As a suggestion for future work is the idea of expanding this study for the remaining hours and days of the week, working, first, the statistical question of inherent variability and then indicators of performance of queues. In addition, other performance metrics can be calculated and presented, mainly in relation to the probability of occurrence of orders, estimating the possible percentage of equilibrium of the system.

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APPENDIX

Appendix A: Graphs with the upper and lower limits set at ± 2 standard deviations of (a) cumulative service time per hour and (b) accumulated service time per hour and by day of the week.

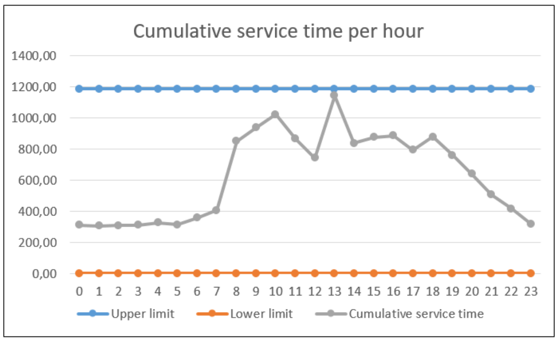

Figure 6: Series (a): Cumulative service time per hour

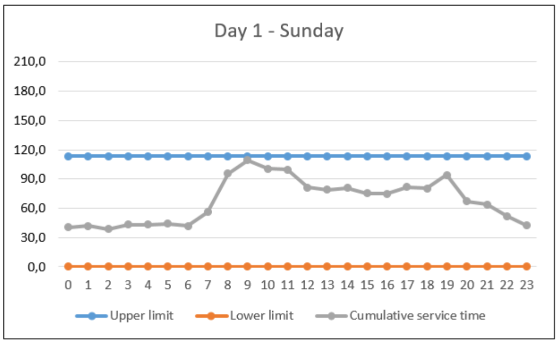

Figure 7: Series (b): Cumulative service time per hour for day 1

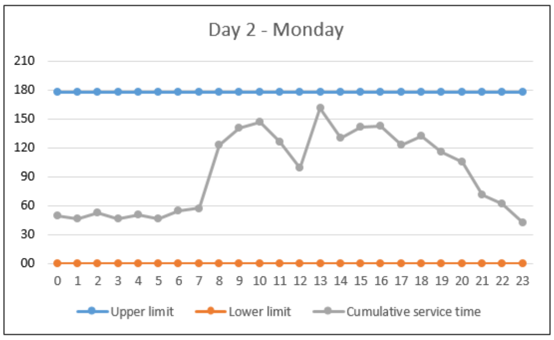

Figure 8: Series (b): Cumulative service time per hour for day 2

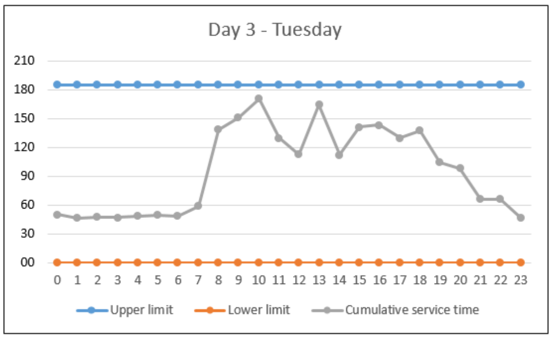

Figure 9: Series (b): Cumulative service time per hour for day 3

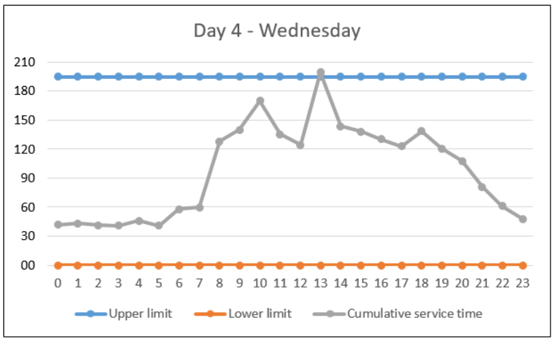

Figure 10: Series (b): Cumulative service time per hour for day 4

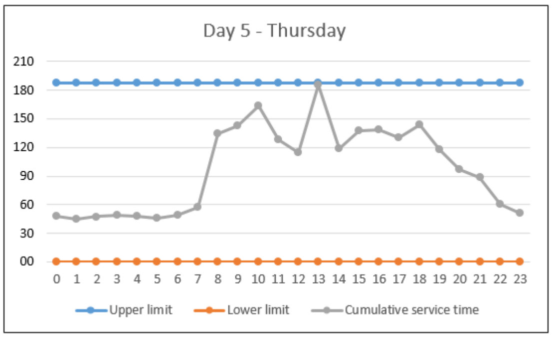

Figure 11: Series (b): Cumulative service time per hour for day 5

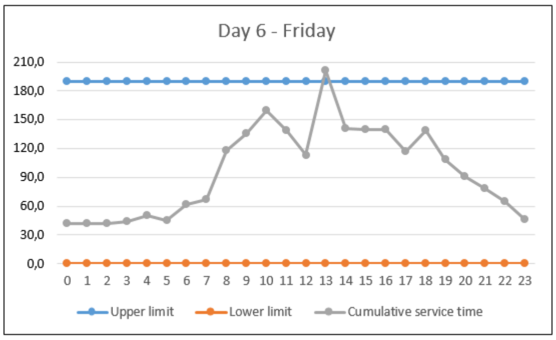

Figure 12: Series (b): Cumulative service time per hour for day 6

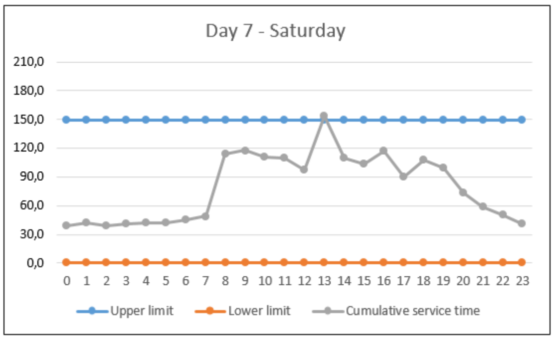

Figure 13: Series (b): Cumulative service time per hour for day 7