Improve the Efficiency of Sample Collection and Analysis in Service Orders Request Using Markov Chains

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Abstract

LabChem'S Corp. in Mayagüez, Puerto Rico, is facing challenges with long waiting times and delays in sample delivery due to their telephone-based service request management system. To address these issues and improve their operational efficiency, the company is exploring using Markov chains to establish order request transition probabilities. This methodology has been successfully used in other supply chain projects to minimize costs and improve lead times. Then, can LabChem'S Corp. make its process efficient by knowing in advance (the next 2 to 4 weeks) order request transition probabilities while drivers are already on the route? Our project aims to design and implement a streamlined service request management system that will enhance LabChem'S Corp.'s sample collection and analysis process. For example, the highest transition probabilities for the fourth week were 0.3874 (April) and 0.3229 (May) for transitions between states 2-3 and 4-3. These results suggest that efforts should be focused on preventing events originating in states 2, 3, and 4. Ultimately, this proposed service request management system could serve as a valuable model for other companies seeking to improve their competitiveness in the marketplace.

Keywords
Service Orders Request, Markov Chain, Chapman-Kolmogorov Equations, n-step Transition Probabilities, and Laboratory Operations Improvement

1. Introduction

This research aims to address the problem of LabChem'S Corp., a company located in Mayagüez, Puerto Rico, which currently uses a telephone-based system for requesting sample collection and analysis services. This method results in long wait times for customers because there is no set limit for service requests. The problem is compounded by the fact that drivers are assigned to customers on a first-come, first-served basis, which disrupts their daily routes and delays the samples' delivery to the laboratory. The motivation for solving this problem is to improve LabChem'S Corp.'s service quality and customer satisfaction and to increase the company's competitiveness in the marketplace. Markov Chains are proposed to calculate transition probabilities for the current system order request events and reduce waiting times in this research. Then, can LabChem'S Corp. make its process efficient by knowing in advance (the next 2 to 4 weeks) order request transition probabilities while drivers are already on the route?

We will describe the current system used by LabChem'S Corp., the limitations and problems associated with it, and the potential benefits of the new service request management process design. We will also discuss the importance of this study in terms of its potential to serve as a model for other companies facing similar service request management challenges. This research aims to design a new company service request management process to reduce waiting times and streamline the sample collection and analysis. In addition, by improving LabChem'S Corp.'s efficiency and effectiveness, we hope to enhance the company's reputation and customer satisfaction.

1.1 Objectives

- Use Chapman-Kolmogorov equations to calculate n-step transition probabilities for a Markov Chain and use this information to make informed decisions and improve process efficiency.

- Design a new service request management process for LabChem'S Corp. to improve efficiency, reduce waiting times, and increase customer satisfaction.

- Identify and prioritize critical areas for improvement in the LabChem'S Corp. service request process and develop an action plan to address these areas.

2. Literature Review

Other organizations have followed suit by incorporating Markov Chains into their optimization and problem-solving efforts, as have the researchers in this study, who have employed this approach to improve the efficiency of their processes. Rahman et al. (2019) used a Markov decision process to optimize emergency department patient flow and resource allocation, improving patient satisfaction and reducing wait times. Luo et al. (2020) conducted a comprehensive study exploring the application of Markov decision processes in healthcare decision-making, including emergency department management, disease management, and drug treatment. The authors conclude that Markov decision processes provide valuable information and contribute to improved healthcare decision-making. White and Sontag (2015) employ Markov decision processes to minimize costs and improve lead times in supply chain operations. Silva et al. (2017) used Markov chains to analyze customer flow and optimize seating arrangements, ultimately improving customer satisfaction. Finally, Araya et al. (2016) employ Markov Chain Monte Carlo methods for predicting power outages and optimizing maintenance schedules, reducing the frequency and duration of power outages. These researches illustrate the versatility and effectiveness of the Markov Chain in addressing operational challenges in various industries.

3. Methodology

In this study, we employed Markov Chain to investigate the operational efficiency of a sampling process in LabChem'S Corp. The data was collected through observation and interviews.

3.1 Markov Chains

According to the Markovian property, the conditional probability of any future event, given any past events and the current state $X_t = i$, depends only on the current state and is independent of the previous events. In Markov Chains, conditional probabilities are called n-step transition probabilities. The n-step transition matrix is a practical method of displaying all the n-step transition probabilities (Hillier and Lieberman 2021).

3.2 Chapman-Kolmogorov Equations

The Chapman-Kolmogorov equation describes the connection between the transition probabilities of a Markov chain along a series of steps. An approach for calculating the probabilities of n-step transitions is provided by Chapman-Kolmogorov Equations (Hillier and Lieberman 2021):

$$\begin{aligned} \mathbf{P}^{n} &= \mathbf{P}\mathbf{P}^{(n-1)} = \mathbf{P}^{(n-1)}\mathbf{P} \\ &= \mathbf{P}\mathbf{P}^{(n-1)} = \mathbf{P}^{(n-1)}\,\mathbf{P} \\ &= \mathbf{P}^{n}. \end{aligned}$$

4. Data Analysis

Transition matrices were performed to determine the n-step transition probabilities of service request events for two study months, April and May 2023.

4.1 April 2023 Results

Table 1 shows service requests collected during the first week of April 2023 categorized by states:

- **State 1-Pending Service Requests:** This state means that pending requests were not attended to the previous day. That is why they became pending requests the next day since there was insufficient time to attend them.
- **State 2-Pending Service Request Before or at 8:00 a.m.:** These requests come in early or at 8:00 a.m. Which is the time that the lab manager verifies the requests and creates the routes to assign them to their two drivers.

- **State 3-Pending Service Request Without Driver Having Left Yet:** The requests come in after the route has already been created. However, the drivers are still in the lab, preparing to start their route for the day. Since they are still in the lab, the request that came in during that time is assigned to one of the two drivers.

- **State 4-Pending Service Request with Driver Already Assigned:** This happens when the requests enter, but the route is already started. That is when the drivers have already left the laboratory where it is assigned to a driver already in the middle of the day, or if the time is not given, it becomes a pending request the next day.

Table 1. Service Request per Week (April 2023)

States	Pending Service Requests	Pending Service Request Before or at 8:00 a.m.	Pending Service Request Without Driver Having Left Yet	Pending Service Request with Driver Already Assigned	Total
Pending Service Requests	2	4	3	2	**11**
Pending Service Request Before or at 8:00 a.m.	0	2	2	1	**5**
Pending Service Request without Driver Having Left Yet	1	1	2	1	**5**
Pending Service Request with Driver Already Assigned	0	3	4	3	**10**

Table 2 displays the state service request events' conditional probability for the first week of April. Each service request is treated as a state in the Markov Chain.

Table 2. Transition Probabilities for each Sequence of Service Request (April 2023)

States	Pending Service Requests	Pending Service Request Before or at 8:00 a.m.	Pending Service Request Without Driver Having Left Yet	Pending Service Request with Driver Already Assigned	Total
Pending Service Requests	0.18	0.36	0.27	0.18	**1.00**
Pending Service Request Before or at 8:00 a.m.	0.00	0.40	0.40	0.20	**1.00**
Pending Service Request without Driver Having Left Yet	0.20	0.20	0.40	0.20	**1.00**
Pending Service Request with Driver Already Assigned	0.00	0.30	0.40	0.30	**1.00**

Figure 1 shows a four-state transition matrix. Each column represents the transition probability from the current state (row states) to the column states. Higher transition probabilities occur from state 2 to state 3. Since the results do not favor the process, there are areas of opportunity to improve its quality, such as avoiding customers making service requests when the route is already planned, which is utterly unfavorable to the company. In addition, because there are changes in the route, it adds more time to them, impacting the customers who have already placed their orders in advance. They are also changing their delivery times, quality, and process commitment, decreasing customer satisfaction and revenue.

$$P = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{cccc} 1 & 2 & 3 & 4 \\ \hline 0.18 & 0.36 & 0.27 & 0.18 \\ 0.00 & 0.40 & 0.40 & 0.20 \\ 0.20 & 0.20 & 0.40 & 0.20 \\ 0.00 & 0.30 & 0.40 & 0.30 \end{array}$$

Figure 1. Transition Matrix

Figure 1 shows the transition probabilities of passing from one state to the other.

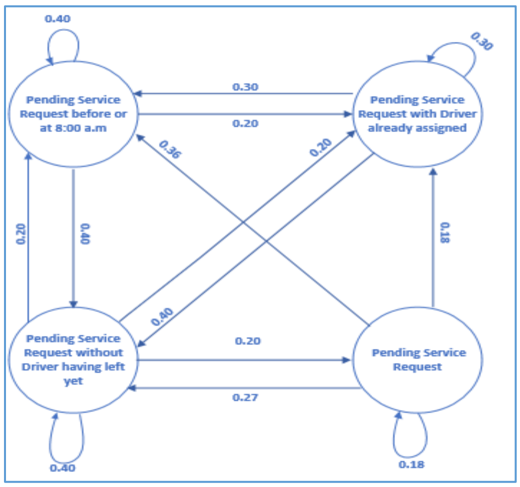

Figure 2. Transition Diagram

The following research questions were answered using an n-step transition matrix:

A. If LabChem'S Corp. starts the day with pending service requests, what are the chances that a pending service request will arise during the day and be made before 8:00 a.m. two weeks later?

```
octave:1> p= [ 0.18 0.36 0.27 0.18; 0.00 0.40 0.40 0.20; 0.20 0.20 0.40 0.20; 0.00 0.30 0.40 0.30]
p =

   0.1800   0.3600   0.2700   0.1800
        0   0.4000   0.4000   0.2000
   0.2000   0.2000   0.4000   0.2000
        0   0.3000   0.4000   0.3000

octave:2> p^2
ans =

   0.086400   0.316800   0.372600   0.212400
   0.080000   0.300000   0.400000   0.220000
   0.116000   0.292000   0.374000   0.216000
   0.080000   0.290000   0.400000   0.230000
```

Figure 3. Octave Calculations for $P^{(2)}$

We have a probability of 0.3168 that a service request be made before 8:00 a.m. (See Figure 3).

B. If LabChem'S Corp. starts the day with pending service requests, what are the odds during the day that a service request enters the system and no driver is assigned? We will have a transition probability of 0.2124 that a service request will arise without a driver being assigned (See Figure 3).

C. What is the probability of doing any services in the fourth week?

```
octave:1> p=[ 0.18 0.36 0.27 0.18; 0.00 0.40 0.40 0.20; 0.20 0.20 0.40 0.20; 0.00 0.30 0.40 0.30]
p =

   0.1800   0.3600   0.2700   0.1800
        0   0.4000   0.4000   0.2000
   0.2000   0.2000   0.4000   0.2000
        0   0.3000   0.4000   0.3000

octave:2> p^4
ans =

   0.093023   0.292807   0.383225   0.217381
   0.094912   0.295944   0.387408   0.219992
   0.094046   0.296197   0.386298   0.219342
   0.094912   0.295844   0.387408   0.220092
```

Figure 4. Octave Calculations for $P^{(4)}$

During the fourth week (Figure 4), the highest transition probability (0.3874) occurs going from state 2 to state 3 and from state 4 to state 3. Therefore, efforts should be made to mitigate the causes that make these states happen.

4.2 May 2023 Results

Table 3 shows service requests collected during the second week of May 2023, categorized by state.

Table 3. Service Request per Week (May 2023)

States	Pending Service Requests	Pending Service Request before or at 8:00 a.m.	Pending Service Request without Driver having left yet	Pending Service Request with Driver already assigned	Total
Pending Service Requests	1	2	1	3	**7**
Pending Service Request before or at 8:00 a.m.	2	2	1	3	**8**
Pending Service Request without Driver having left yet	0	1	3	1	**5**
Pending Service Request with Driver already assigned	1	3	3	4	**11**

Table 4 displays the state service request events' conditional probability for the second week of May 2023.

Table 4. Transition Probabilities for each Sequence of Service Request (May 2023)

States	Pending Service Requests	Pending Service Request before or at 8:00 a.m.	Pending Service Request without Driver having left yet	Pending Service Request with Driver already assigned	Total
Pending Service Requests	0.14	0.29	0.14	0.43	**1.00**
Pending Service Request before or at 8:00 a.m.	0.25	0.25	0.13	0.37	**1.00**
Pending Service Request without Driver having left yet	0.0	0.20	0.60	0.20	**1.00**
Pending Service Request with Driver already assigned	0.09	0.27	0.27	0.36	**1.00**

The matrix in Figure 7 shows a four-state transition matrix. Higher transition probabilities occur from state 1 to state 4.

$$
\mathbf{P} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array}
\begin{array}{c}
\begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
\begin{bmatrix}
0.14 & 0.29 & 0.14 & 0.43 \\
0.25 & 0.25 & 0.13 & 0.37 \\
0.00 & 0.20 & 0.60 & 0.20 \\
0.09 & 0.27 & 0.27 & 0.36
\end{bmatrix}
\end{array}
$$

Figure 5. Transition Matrix

Figure 5 shows more graphically how these states behave to help visualize them. Again, arrows indicate from which state to which state was moved along with the transition probability of that occurrence above the arrow.

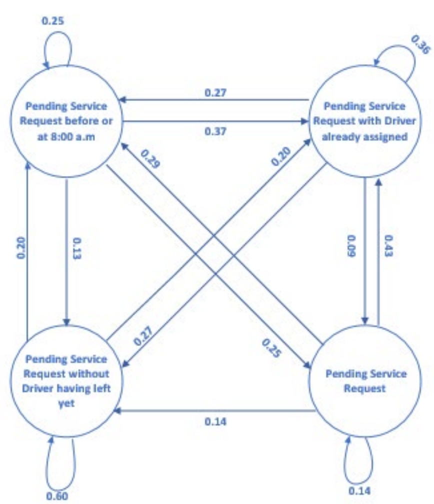

Figure 6. Transition Diagram

We answered the research questions with the new data.

A. If LabChem'S Corp. starts the day with pending service requests, what are the chances that a pending service request will arise during the day and be made before 8:00 a.m. two weeks later?

```
octave:2> p=[0.14,0.29,0.14,0.43;0.25,0.25,0.13,0.37;0.0,0.20,0.60,0.20;0.09,0.27,0.27,0.36]
p =

   0.1400   0.2900   0.1400   0.4300
   0.2500   0.2500   0.1300   0.3700
        0   0.2000   0.6000   0.2000
   0.0900   0.2700   0.2700   0.3600

octave:3> p^2
ans =

   0.130800   0.257200   0.257400   0.350300
   0.130800   0.260900   0.245400   0.359200
   0.068000   0.224000   0.440000   0.266000
   0.112500   0.244800   0.306900   0.322200

octave:4> p^4
ans =

   0.107662   0.244156   0.317548   0.319541
   0.108332   0.244612   0.315907   0.320545
   0.098039   0.239608   0.347708   0.307026
   0.103852   0.240423   0.322951   0.312789
```

Figure 7. Octave Calculations for $P^{(2)}$ and $P^{(4)}$

We have a probability of 0.2441 that a service request be made before 8:00 a.m. (See Figure 7).

B. If LabChem'S Corp. starts the day with pending service requests, what are the odds during the day that a service request enters the system and no driver is assigned? We will have a transition probability of 0.3195 that a service request will arise without a driver being assigned (See Figure 7).

C. What is the probability of doing any services in the fourth week? One of the highest transition probabilities (0.3229) occurs from state 4 to state 3 (Figure 7).

4.3 Comparative April vs. May 2023

Comparing the April and May data, we can observe differences in LabChem'S Corp. transition probabilities. For example, in the first scenario (April 2023), the probability that a pending service request will be made before 8 a.m. two weeks later is 0.3168. Meanwhile, in the second scenario (May 2023), the probability decreases to 0.2441.

For the probability of a service request entering the system without a driver being assigned, the transition probability is 0.2124 in the first scenario. Meanwhile, in the second scenario, it increases to 0.3195. The above shows that there has been an increase in the transition probability of the service requests made without a driver being assigned from April to May.

When considering the probability of performing any of the services in the fourth week, there is a slight variation between the two data sets. In the first scenario, the highest transition probability is 0.3874, occurring from state 2 to state 3 and from state 4 to state 3. The second scenario's highest transition probability is 0.3229, from state 4 to state 3. Therefore, LabChem'S Corp needs to analyze and understand these differences to make informed decisions and mitigate potential problems.

5. Proposed Improvements

Based on the analysis, there are chances to improve the process's quality. One approach could be implementing a mechanism that validates the route's availability before accepting service requests. This would prevent consumers from making service requests while the route is already in motion, which could result in route adjustments and lengthier delivery times. Furthermore, this would help to maintain the process's commitment and quality, resulting in higher customer satisfaction and increased revenue for the company.

Another option is to strengthen customer contact channels, alerting them of the status of their service requests and providing information on any changes in the route. This would aid in managing customer expectations. Given the time and budget constraints to improve this process, a service request template was created for customers, which is accompanied by specifications that requests must be made at least 8 hours before the desired service time. With these specified limits and the template for customers to request their services, the efficiency of the process is improved, as well as communication between the company and the customer. In addition, they are eliminating the need for a call system to communicate with the company, which can fail if employees are unavailable 24/7. This also helps customers avoid the limitations of calling specifically during LabChem'S Corp. service hours and increases reliability with the customer.

By submitting their requests in advance, customers ensure that their order will be included in the next trip that the drivers make. In addition, this format will be used to stipulate time limits for submitting requests and reduce pending requests (Figure 10). Help the laboratory manager who makes and assigns routes to know in advance which customers made requests and to determine if he can fulfill that work during the day. Otherwise, he can warn the customer in advance that his order will be served the next day since it will be served on a first-come, first-served basis.

Markov Chains and n-step transition probabilities helped to give direction to the problem and show LabChem'S Corp. how these events affected the process. By using the transition probabilities, the company was able to anticipate if this behavior would continue to happen in the requests and put an end to it. They are improving efficiency in the process since it affects the delivery time. This improvement helps to eliminate those waiting times for samples to be analyzed. Because in the company's current process, there are risks associated when the samples spend too much time out of the required conditions. This could lead to a loss since when taking orders during the route has already started, it is more time for those customers who have already made their orders in advance to wait longer due to poor coordination of service requests. Knowing these probabilities in advance confirms to the laboratory that they must solve this problem. Since it was probabilistically proven that it would continue to occur and there would be more losses and longer waiting times for the customers.

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Thank you for trusting our laboratory sample collection services. To request our services, please fill out the following information and send it to our email address at least **8 hours** before you need the samples to be collected:

Client name:
Company:
Contact number:
Pick-up address:
Pick-up Day and time:
Number of samples:
Special instructions:

Please note that a confirmation email will be sent to you once your request has been processed. If you have any questions or need to make changes to your request, please contact us through our contact number.

Thank you for choosing our services.

Sincerely,

Labchem'S Corp

Figure 8. Template for Service Request

6. Future Work

For future work, it was proposed that the company implement an automated digital system that allows customers to place orders and check their status. In addition, it will notify them when their order has been processed, and a driver has been assigned to their route. This work is expected to improve the quality of the process and customer reliability. This is ultimately the most important thing for the company to attract more customers and, as a result, improve revenues throughout this process.

7. Conclusion

In this research, we propose using Markov Chains to improve the service request process of LabChem'S Corp. and reduce their waiting times. By analyzing data and applying n-step transition probabilities and Chapman-Kolmogorov Equations from Markov Chains, we set the grounds for the company so they can improve their efficiency. Performing this analysis, LabChem'S Corp. could also improve its service request process, reduce waiting times, and increase customer satisfaction. Furthermore, the company can use the Chapman-Kolmogorov equations to calculate the n-step transition probabilities for a Markov chain and use this information to make informed decisions and improve the efficiency of the process.

The design of this new service request management process for LabChem'S Corp. will increase efficiency, reduce waiting times, and increase customer satisfaction. It also will facilitate identifying and prioritizing the improvement of critical areas inside the company's service request process and develop an action plan to address these areas of concern. By analyzing the transition probabilities associated with different scenarios, we were able to identify areas of opportunity and develop strategies that will be useful to improve the quality of the process. These strategies included strengthening customer communication channels, implementing a service request template, and establishing clear request timelines.

When comparing April and May data, we observed variations in transition probabilities associated with LabChem'S Corp. service requests. This data analysis exercise reinforced the importance of proposed improvements, such as validating route availability and improving customer communication channels. In addition, the analysis helped LabChem'S Corp. understand the impact of these events on the process and enabled it to make informed decisions to improve efficiency and turnaround times. Therefore, by applying Markov Chains and analyzing the data, we provided LabChem'S Corp. with valuable information and recommendations to improve its service request process. The proposed improvements are intended to increase customer satisfaction, optimize operations, and contribute to the overall success of LabChem'S Corp. In general, we can determine that the framework and strategies suggested in this research will help the company to meet the proposed objectives. Furthermore, the n-step transition probabilities obtained were essential to compare and carry forward to future weeks. Therefore, the company could monitor if they went up or down. The purpose is to demonstrate that if these transition probabilities continue to increase shortly, they directly affect the customer by increasing the waiting time to attend to their requests and decreasing LabChem'S profits.

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Biographies

Maria Y. Rivera González is a 24-year-old industrial engineering student with an associate degree in quality control engineering. She is in her final year of a bachelor's degree in industrial engineering and is certified as a yellow belt. She aspires to secure a position in an industry as an engineer to showcase her knowledge acquired at Ana G. Mendez University in Gurabo.

Juan E. Rosa Serrano Is a student of 23 years old in their fourth year of college studying Industrial Engineering and Management at Ana G. Mendez University. I completed an associate degree in Quality Control Engineering at the Gurabo campus one year ago. Throughout these years, I have gained experience in many new things, which will help me become a great professional in the work field.

Yesenia Cruz Cantillo, Ph.D., MSIE, MECE, is an Industrial Engineer with a master's degree in industrial engineering focused on Quality Systems and expertise in Quality Control Systems. With 6 years of experience developing, evaluating, and implementing quality management systems, she used ISO 9000 standards and statistical analysis applied to several production and service processes. She also holds a Ph.D. in Civil/Transportation Engineering, with a Master's Degree in Transportation Engineering and strong abilities in simulation. In addition, she has over 17 years of experience in research and teaching and almost 8 years of experience in Transportation Consulting. Strong background in production engineering with expertise in improving information systems using informatics and production planning and control.