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Research Article

The Impact of Dynamic Shocks and Special Days on Time Series Data

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Abstract:

This paper includes an examination of a 4-year time series data on retail delivery demand generated by a logistics company based on the dates of creation. The periodic fluctuations observed in the data's normal structure are caused by the accumulation of demands over the weekend and their fulfillment at the beginning of the week. The aim of the study is modeling the response to unexpected changes in demand, which we refer to as "shocks," similar to the weekend effect. Special days, including single-day public holidays, religious holidays, and campaign periods in November, which represent specific periods, were also analyzed to interpret the patterns during these periods. The patterns created by single-day public holidays and religious holidays are significantly influenced by whether these days fall on a weekend or a weekday. By excluding weeks with special days from the overall data, the presence of shock effects in the remaining ordinary weeks was examined. During this period, the shock caused by the Covid-19 pandemic and adverse weather conditions was observed. The impact of the Covid-19 shock lasted longer compared to other shocks. When the increase in demand due to shocks exceeds the capacity of existing vehicles, the problem can be resolved by arranging daily rental vehicles from companies that provide vehicle allocations. Extracting the demand model for special days and unexpected shocks will ensure operational preparedness and prevent process delays. When ordinary weeks were examined, a monotonically decreasing trend from Monday to Sunday was observed based on the weekly average demand. The maximum demand was 58.3% on Monday, 17.2% on Tuesday, 15.9% on Wednesday, 7.3% on Thursday, and 1.3% on Friday. The provided graphs also demonstrate a significant increase in demands in early 2020 due to the widespread adoption of e-commerce as a result of the Covid-19 pandemic.

1. Introduction

In this study, a 4-year time series data on retail delivery demand based on the creation dates were analyzed in a logistics company, covering the years 2019-2022. The data was normalized and analyzed. It covers a 207-week time range starting from the first Monday of 2019 and ending on the last Sunday of 2022. The study examines the patterns created by special days and discount campaigns, as well as the dynamic shocks resulting from unexpected events.
The daily demand counts in the data were analyzed on a weekly basis, and the averages and standard deviations were calculated for each day of the week. The results are shown in Figure 1. Figure 1 illustrates that the daily averages decrease monotonically from Monday to Sunday (Monday: 56910, Tuesday: 52790, Wednesday: 50977, Thursday: 48835, Friday: 47318, Saturday: 39445, Sunday: 27456). In the literature, some studies investigate the impact of shocks on time series data. For instance, in the article [1], the effect of oil price shock on time series data was examined. The study focused on analyzing the influence of oil price shocks on the observed time series data. Furthermore, [2] conducted a study to measure the dynamic shock effects in time series data using a non-parametric approach. Leduc and Liu (2016) examined the shock that affects aggregate demand through the labor market, where increased uncertainty leads to higher unemployment and lower inflation, [3]. In the article [4], the impact of demand shocks in the automotive sector was investigated using data from the San Diego region

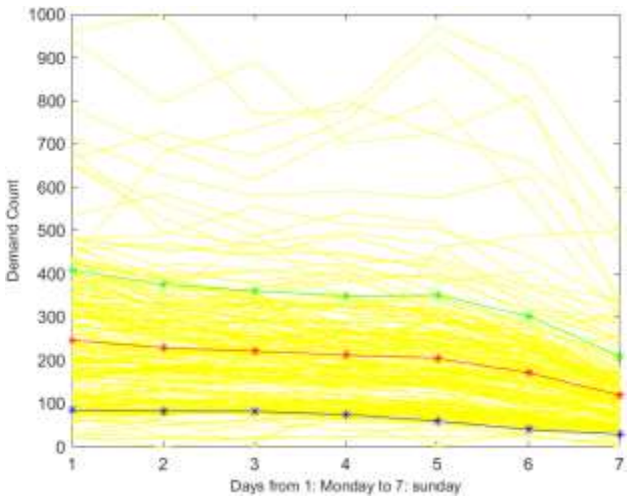

Figure 1. *Yellow: Daily demand counts for 207 weeks. Red: Daily average. Green: Average + standard deviation. Blue: Average - standard deviation.*

and it was found that the 2008-2009 economic crisis led to a decrease in demand.

2. Special Days

Official holidays and campaign days, weekends, or exceptional circumstances, can disrupt the general demand pattern. Official holidays and November discounts are special days that occur on specific dates each year. New Year's Day, April 23rd National Sovereignty and Children's Day, May 1st Labor and Solidarity Day, May 19th Commemoration of Atatürk, Youth and Sports Day, July 15th Democracy and National Unity Day, August 30th Victory Day, October 29th Republic Day, Eid al-Fitr, and Eid al-Adha are official holidays.

2.1 Single-Day Official Holidays

The weeks in which single-day special occasions fall for each year are provided in Table 1. The changes in the daily demand counts for a total of 6 days, including the single-day special occasions given in Table 1, along with 2 days before and 3 days after, were plotted to examine the pattern of these special days. In Figure 2, the impact of New Year's Day on a yearly basis is presented. Here, unlike the others, there is an increase at $x = 2$ for the year 2022. The reason for this is that the day coincides with Monday. Apart from that, patterns can be observed for $x = -1, 0,$ and 1 values. In Figure 3, the impact of April 23rd National Sovereignty and Children's Day on a yearly basis is presented. Here, unlike the others, there is an increase at $x = 2$ for the year 2022. The reason for this is that the day coincides with Monday. Apart from that, patterns can be observed for $x = -1, 0,$ and 1 values. In Figure 4, the impact of May 1st Labor and Solidarity Day on a yearly basis is presented. Compared to the year 2021, the pattern is shifted by one day in the year 2022, and reason for this is that the value $x = 1$ in 2022 corresponds to the start of Eid al-Fitr (Ramadan Bayram). In the year 2020, the declines continue after May 1st, and this is because these two days coincide with the weekend. In Figure 5, the impact of the May 19th Commemoration of Atatürk, Youth and Sports Day on a yearly basis is presented. In 2019, 2020, and 2021, there are patterns observed for $x = -1, 0,$ and 1 values. However, unlike the others, in the year

Table 1. *Table of weeks and days in which one-day special days are included. (Mon: Monday; Tues: Tuesday,; Wed: Wednesday; Thurs: Thursday; Fri:Friday; Sat: Saturday; Sun:Sunday)*

Single-day special days	**2019**	**2020**	**2021**	**2022**
New Year's Day	0. week Tues	52. week Wed	104. week Fri	156. week Sat
April 23rd National Sovereignty and Children's Day	16. week Tues	68. week Thurs	120. week Fri	172. week Sat
May 1st Labor and Solidarity Day	17. week Wed	69. week Fri	121. week Sat	173. week Sun
May 19th Commemoration of Atatürk, Youth and Sports Day	19. week Sun	72. week Tues	124. week Wed	176. week Thurs
July 15th Democracy and National Unity Day	28. week Mon	80. week Wed	132. week Thurs	184. week Fri
August 30th Victory Day	34. week Fri	86. week Sun	139. week Mon	191. week Tues
October 29th Republic Day	43. week Tues	95. week Thurs.	147. week Fri	199. week Sat

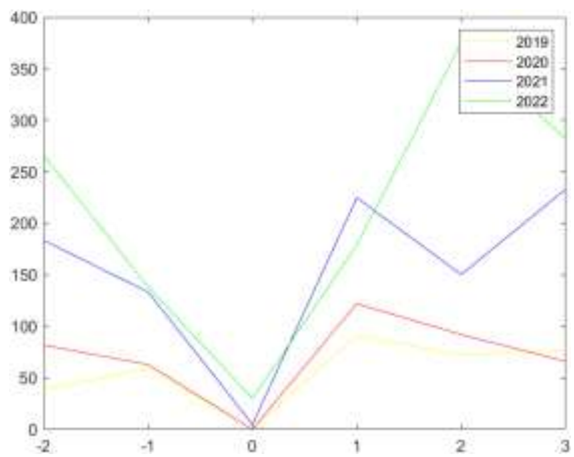

Figure 2. *6 days of data including the New Year on January 1 by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

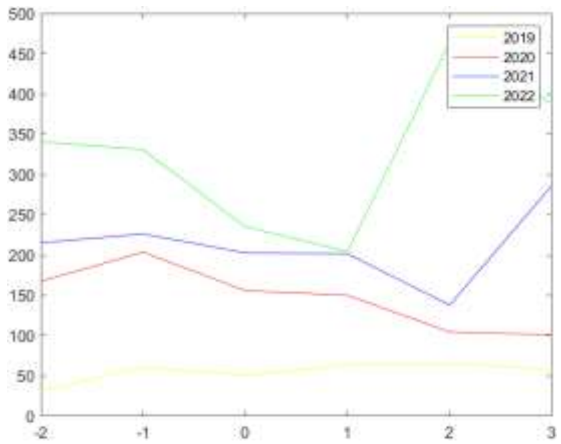

Figure 3. *6 days of data including the April 23rd National Sovereignty and Children's Day by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

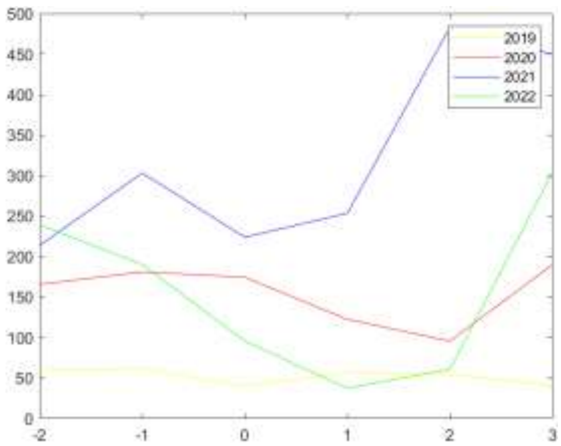

Figure 4. *6 days of data including the May 1st Labor and Solidarity Day by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

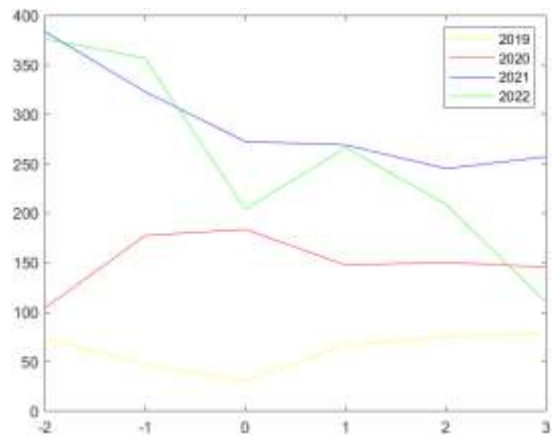

Figure 5. *6 days of data including the May 19th Commemoration of Atatürk, Youth and Sports Day by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

2022, there is a significant decline at $x = 2$ and $x = 3$ values, and the reason for this is that it coincides with the weekend. In the year 2020, the special day falls on Tuesday, and no decline is observed. This date corresponds to the week before Eid al-Fitr (Ramadan Bayram), and the absence of decline may be due to the high demand before the holiday. Figure 6 illustrates the impact of July 15th Democracy and National Unity Day on a yearly basis. In the years 2020, 2021, and 2022, there are patterns observed for $x = -1, 0,$ and 1 values. In the year 2019, at $x = -1$, it is expected to be low as it coincides with Sunday. Figure 7 presents the impact of August 30th Victory Day on a yearly basis. In the years 2020 and 2022, there are patterns observed for $x = -1, 0,$ and 1 values. In the year 2019, at $x = 1$ and $x = 2$, it is expected to be low as they coincide

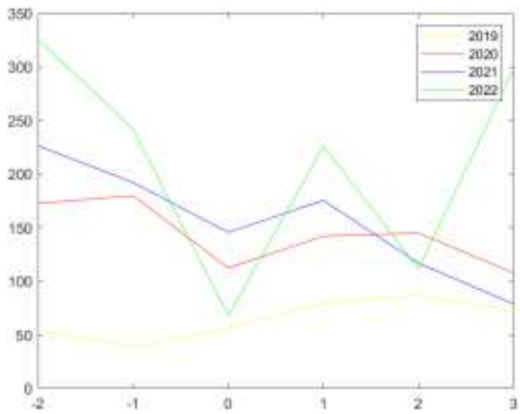

Figure 6. *6 days of data including the July 15th Democracy and National Unity Day by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

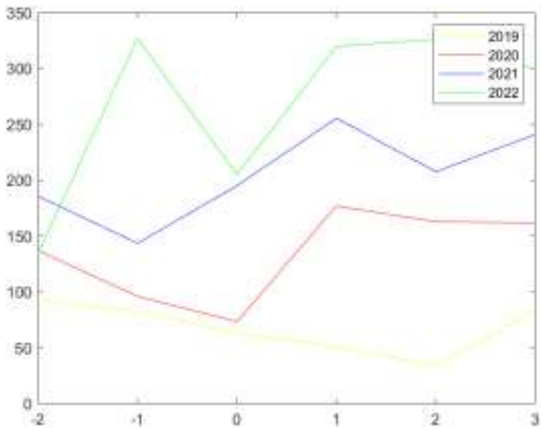

Figure 7. *6 days of data including the August 30th Victory Day by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

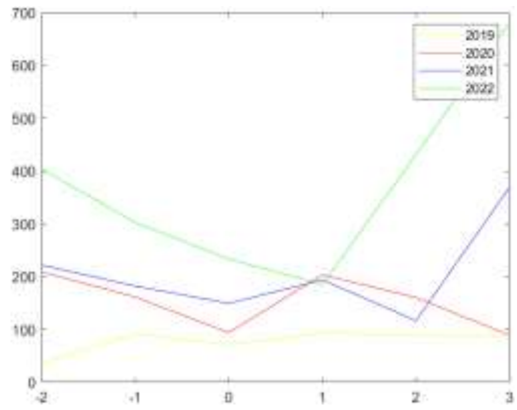

Figure 8. *6 days of data including the October 29th Republic Day by year (0 on the x-axis denotes the special day, others 2 days before and 3 days after)*

with the weekend, and in the year 2021, at $x = -1$, it is expected to be low as it falls on Sunday.

Figure 8 illustrates the impact of October 29th Republic Day on a yearly basis. In the years 2019, 2020, and 2021, patterns can be observed for $x = -1, 0,$ and 1 values. In the year 2022, at $x = 1$, it is expected to have a decrease as it falls on Sunday. In this part, it has been observed that, except for exceptions, there is an impact on the following days of one-day special holidays, indicating a decrease on these special days followed by a one-day increase effect. Special days create a $'V'$ shaped pattern, with a decrease one day before and an increase one day after the special day.

2.2 Religious Holidays

The tables indicating the weeks containing Eid al-Fitr and Eid al-Adha for each year are presented in Table 2 and Table 3, respectively. To examine the patterns of religious holiday breaks, figures including 8 days prior and 10 days following these special days have been plotted and shown in Figure 9 and Figure 10, respectively. In Figure 9, the first day of Eid al-Fitr for four years is represented as $x = 0$, the second day as $x = 1$, and the third day as $x = 2$. $x = -1$ and $x = -7$ correspond to one day and seven days before the first day of the holiday, respectively. $x = 3,4,5,6,7,8,$ and 9 represent the days following the holiday. In Figure 9, a pattern can be observed for $x = -1,0,1$ values. However, in contrast to other years, there is a continued decrease for $x = 1$ in the year 2022. In Figure 10, the first day of Eid al-Adha for four years is represented as $x = 0$, the second day as $x = 1$, the third day as $x = 2$, and the fourth day as $x = 3$. $x = -1$ and $x = -7$ correspond to one day and seven days before the first day of the holiday, respectively. $x = 4,5,6,7,8,9,$ and 10 represent the days following the holiday. In Figure 10, a pattern can be observed for $x = -1,0,1$ values in years other than 2022. However, in the year 2022, there is a continued decrease for $x = 1$ and $x = 2$ as well. In this section, it can be seen that there is a pattern for $x = -1,0,1$ values in religious holidays, except for the year 2022. In 2022, there has been less activity following the first days of the religious holidays compared to other years. Overall, the first day of religious holidays, one day before, and one day after create a $'V'$ shaped pattern.

2.3 November Discount Period

Regular discount campaigns take place in November every year. Table 4 presents five weeks containing November for four years, and the demand graph is illustrated in Figure 11.

Table 2. *Table of the weeks including Eid al-Fitr by year (Mon: Monday; Tues: Tuesday, Wed: Wednesday; Thurs: Thursday; Fri: Friday; Sat: Saturday; Sun :Sunday)*

2019	2020	2021	2022
22. week (Tues, Wed, Thurs)	72. week (Sun)	123. week (Thurs, Fri, Sat)	174. week (Mon, Tues ,Wed)
	73. week (Mon, Tues)		

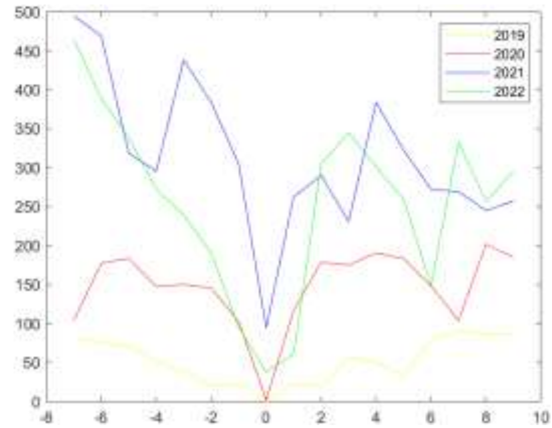

Figure 9. *17 days of data including the Eid al-Fitr by year (On the x-axis, 0 represents the beginning of Eid, minuses represent the days before Eid, 3,4,5,6,7,8 and 9 represent the days after Eid)*

Table 3. *Table of the weeks including Eid al-Adha by year (Mon: Monday; Tues: Tuesday, Wed: Wednesday; Thurs: Thursday; Fri: Friday; Sat: Saturday; Sun: Sunday)*

2019	2020	2021	2022
31. week (Sun)	82. week (Fri, Sat, Sun)	133. week (Tues, Wed, Thurs, Fri)	182. week (Tues, Wed, Thurs, Fri)
32. week (Mon, Tues, Wed)	83. week (Mon)		

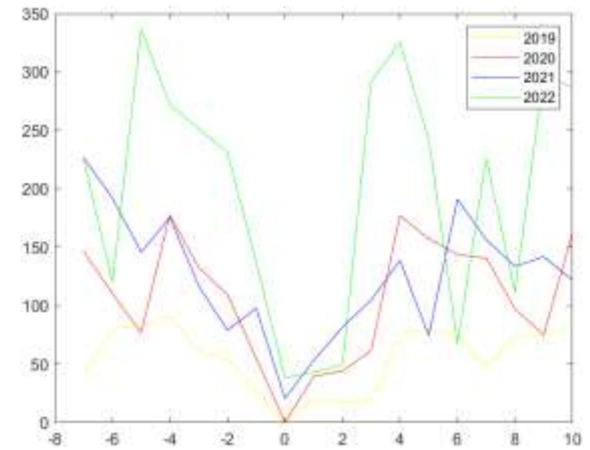

Figure 10. *18 days of data including the Eid al-Adha by year (On the x-axis, 0 represents the beginning of Eid, minuses represent the days before Eid, 4,5,6,7,8,9 and 10 represent the days after Eid)*

Table 4. *Table of weeks containing November by year*

2019	2020	2021	2022
43 week	96. week	148. week	200. week
44. week	97. week	149. week	201. week
45 week	98. week	150. week	202. week
46 week	99. hafta	151. week	203. week
47. week	100. hafta	152. week	204. week

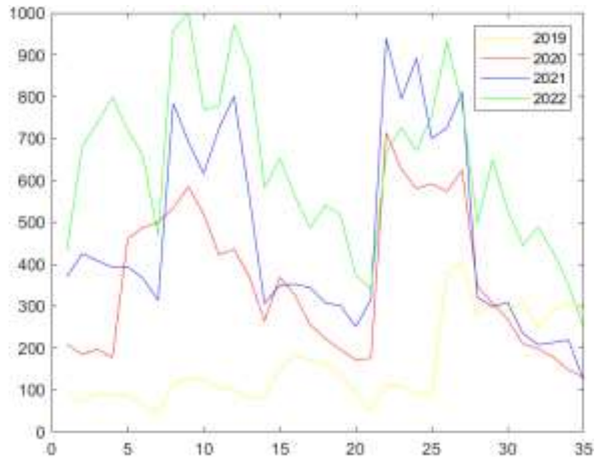

Figure 11. *5 weeks (35 days) demand graph including November by year*

Upon examining Figure 11, a pattern of fluctuations can be observed within a specific period. The demand tends to be low one day before the start of the campaign, while significant demand increases occur as the campaign begins.

3. Weekly Variation

The overall structure of the data forms a weekly fluctuation pattern. The time series data of regular weeks, excluding special days, is plotted in Figure 12.

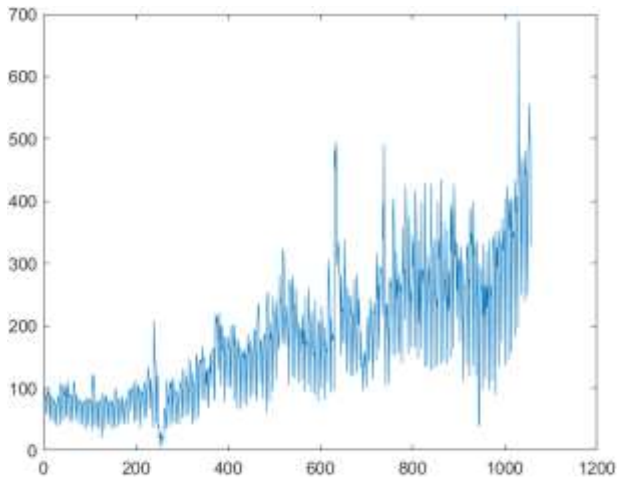

Figure 12. *Normal weeks time series demand graph (151 weeks= 1057 days)*

The results obtained using Discrete Fourier Transform to observe the prominent frequencies in the data shown in Figure 12 are provided in Figure 13. The mathematical representation of the Discrete Fourier Transform is as follows [5]:

$$F(k) = \sum_{n=0}^{N-1} f(n).e^{(-i..2\pi.k.n/_{N})}$$

- $F(k)$: The value obtained for the index k of the frequency component as a result of the Discrete Fourier Transform.
- $f(n)$: The value at index n in the initial time series data.
- N: The length of the initial time series.
- i: The imaginary number $\left(\sqrt{-1}\right)$.

In Figure 13, significant peaks can be observed at $x = 2, x = 152, x = 303,$ and $x = 454$ values. These notable increases at these points indicate the presence of weekly periodic patterns in the data and the strength of these periodicities.

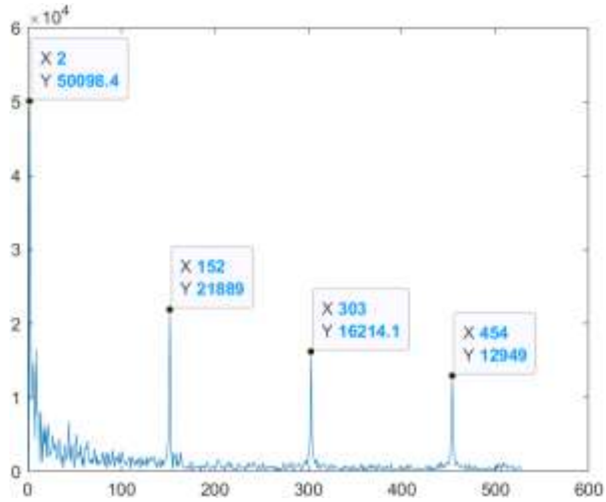

Figure 13. *The figure of peaks in demand during normal weeks.*

3.1 Weekly Average Pattern

In this section, the weekly average demands are examined on a yearly basis and presented in Figure 14.

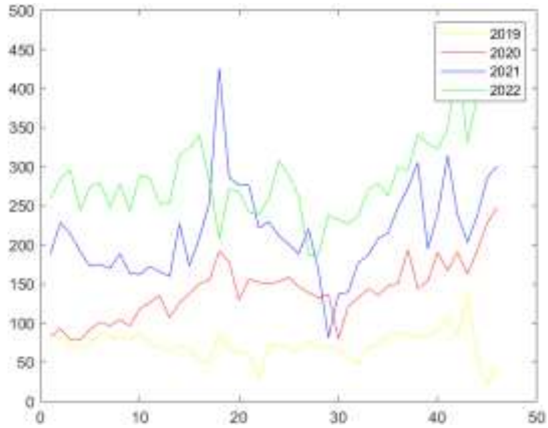

Figure 14. *The figure of weekly average demand*

In Figure 14, a general pattern can be observed. However, in the year 2021, there were significant increases and decreases in the 18th and 29th weeks. The 18th week corresponds to the period between May 3rd and May 9th, during which Summer Shopping and Mother's Day discounts were offered. The 29th week falls between July 19th and July 25th, which includes the dates of the Eid al-Adha. In the year 2019, there were significant drops in the 45th and 46th weeks, attributed to adverse weather conditions such as fog and snowfall. Additionally, Figure 12 shows an increase in demands starting from the first quarter of 2020, which can be attributed to the widespread adoption of E-commerce due to the impact of COVID-19, as mentioned in [6] and [7] articles.

4. Dynamic Shock Effect

Unpredictable factors that occur annually can lead to unexpected increases or decreases in the data. Situations that disrupt the expected patterns are defined as shock effects. In this part, the weeks that include the special days mentioned in Section 2 were excluded from the entire data, and the cases of unexpected shock effects were examined. In Figure 15, when observing the red line representing the averages, a monotonically decreasing pattern from Monday to Sunday can be observed. When examined on a weekly basis, out of the 151 weeks analysed, there were 26 weeks (%17.2) where there was a monotonically decreasing trend from Monday to Sunday. Figure 16 represents the figure for these weeks. Out of the 151 weeks analysed in Figure 15, it was observed that Monday had the

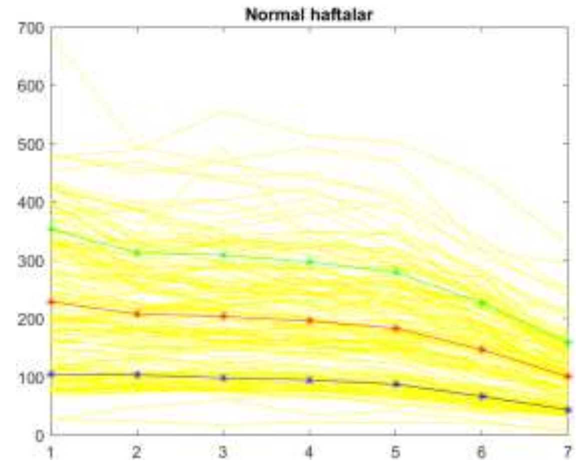

Figure 15. *Yellow: Daily demand numbers of the 151-week data excluding the weeks in Section 2. Red: Daily average. Green: Average + standard deviation. Blue: Average - standard deviation.*

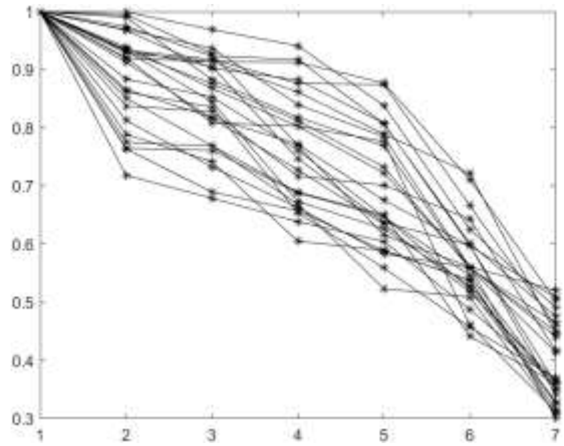

Figure 16. *The figure of weeks with monotonically decreasing days from Monday to Sunday (x-axis represents days of the week, the y-axis represents the ratio of each day to Monday).*

maximum shipment demands in 88 weeks (%58.3), Tuesday in 26 weeks (%17.2), Wednesday in 24 weeks (%15.9), Thursday in 11 weeks (%7.3), and Friday in 2 weeks (%1.3). The weeks with maximum shipment demands on Friday were the 63rd and 66th weeks. In the 63rd week, the demands on weekdays were generally similar to each other. The ratio of Friday's demand to Monday's demand was calculated as 1.1, indicating a negligible difference. In the 66th week, Friday was April 10th. On the night between April 10th and 11th, a two-day nationwide lockdown was announced due to **Covid-19**, and there was a reduction in operations related to bread-making machines in the company. **Covid-19** is an unexpected event that created a shock effect. In Figure 17, the demand figure for the 14 days from Monday of Week 66 to Sunday of Week 67 is

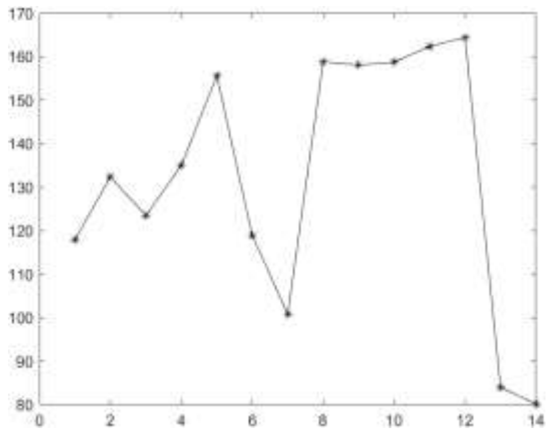

Figure 17. *Weeks 66 and 67: Effect of Covid-19*

depicted. The 2-day lockdown corresponds to the weekend (x=6,7), and it is evident that there is a significant increase in demand in the week following the lockdown (x=8,9,10,11,12). This indicates that the response to the shock lasts longer than a typical weekend response. The ratio of the number of weeks where maximum demand occurs on Tuesday to the number of weeks where maximum demand occurs on Monday is 29.5%, and similarly, the ratio of the number of weeks where maximum demand occurs on Wednesday to the number of weeks where maximum demand occurs on Monday is 27.3%. The difference between Tuesday and Wednesday is not substantial. Therefore, it can be inferred that the backlog of shipment demands over the weekend does not significantly impact the pattern on Tuesday.

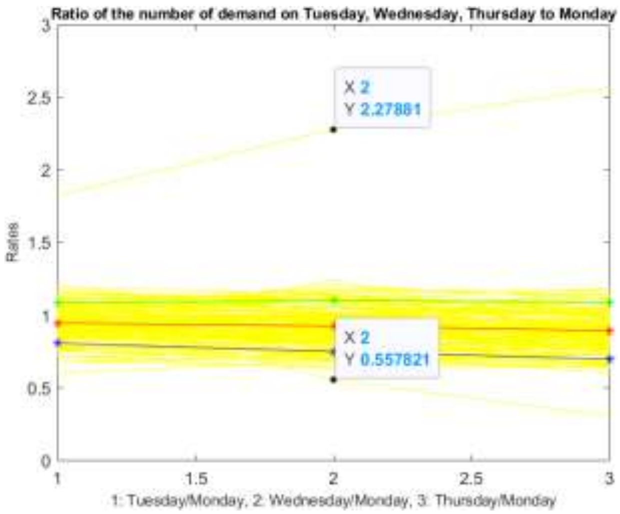

Figure 18. *Yellow: ratios, Red: mean, Green: mean + standard deviation, Blue: mean - standard deviation.*

The ratios of Tuesday, Wednesday, and Thursday to Monday are shown in Figure 18, highlighted in yellow. Additionally, the average of the ratios is depicted in red, the sum of the average and standard deviation of the ratios is shown in green, and the difference between the average and standard deviation of the ratios is represented in blue. The weeks where Wednesday deviates from the general pattern, with ratios of 0.56 and 2.28 to Monday, are weeks 49 and 51, respectively. In week 49, Monday and Tuesday have higher delivery demands compared to other days, resulting in a difference in the ratios. In Week 50, Monday's delivery demand is high, leading to lower ratios for other days. However, there is a general decrease in delivery demand compared to other weeks, and this decline in demand is also present on Monday of Week 51. The dates with low demand are between December 11th and 23rd, 2019. The reason for the low demand during this period is adverse weather conditions such as fog and snowfall. In Week 51, the effect of the shock continues, and the delivery demand is lower compared to other days of the week. Apart from weeks 49 and 51, the ratios of other days to Monday are not significantly different.

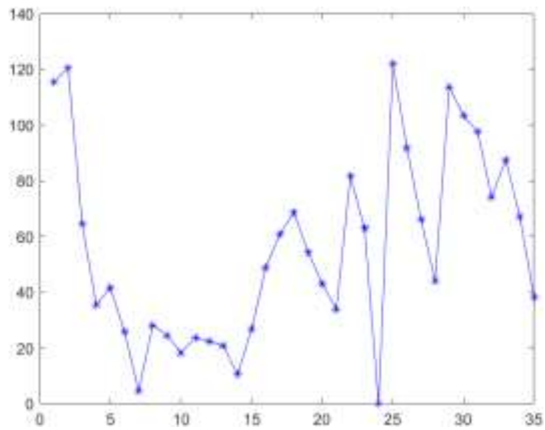

Figure 19. *Weeks 49, 50, 51, 52, and 53: Effect of Fog and Snowfall*

In Figure 19, 35 days is plotted, including weeks 49, 50, and 51, as well as the subsequent weeks 52 and 53, along with the corresponding changes in demand. The decline during weeks 49, 50, and 51 is evident, especially with the fog and snow warning. In Week 52, there is a significant drop on Wednesday due to the New Year holiday, and the impact is strongly observed on the following day. The effect of the New Year holiday was extensively examined in Section 2. After the manifestation of the New Year effect in week 52, demand continued to follow its normal trend in Week 53.

5. Conclusion

November is a period when discounts and fluctuations in demand occur each year. Demand is low one day before the announcement of the discounts and significantly increases after the discounts begin. Several major campaigns are held throughout November, creating a distinct pattern for this month. Official holidays result in a decrease in demand on a respective day and an increase in demand on the following day, thus forming a 'V' pattern for one-day official holidays. On the first day of religious holidays, there is a decrease in demand, followed by an increase in demand on the second day and onwards. Exceptional events that do not recur in the same period each year, such as Covid-19 and adverse weather conditions, also have a disruptive effect on the overall demand pattern. Additionally, the data analysis clearly shows the increase in e-commerce due to the emergence of Covid-19.

As a result of this study, demand fluctuations in response to special days and unexpected circumstances have been identified. In cases where the increase in demand exceeds the capacity of existing vehicles, daily rental vehicles can be arranged from companies that provide such services to solve the problem. Extracting the demand model for special days and unexpected shocks will enable operational preparedness and prevent process slowdowns. The impact of the Covid-19 shock has lasted longer compared to other shocks. This is due to the influence of extraordinary human behavior driven by the idea of stockpiling food and supplies in response to the crisis.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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