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RESEARCH ARTICLE

Assessing Supply Chain Problems Facing Motor Vehicle Manufacturers After COVID-19

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ABSTRACT

Following the COVID-19 pandemic, many studies, mainly relying on qualitative data, assessed its effects on supply chains. This study aimed to investigate the impact of supply chain challenges following the COVID-19 pandemic on commercial vehicle production utilizing real-life data. Production volumes and various cost data from a major Turkish commercial vehicle manufacturer were used in this study. Descriptive statistics and time series models were used to statistically examine the data. Findings reveal that pandemic-related disruptions in the international supply chain not only hindered production processes but also imposed significant economic pressures on manufacturers. Results also revealed that drops in production volumes due to COVID-19 have not yet been fully recovered during the first three years following the pandemic. Implications of the effects of cost hikes due to supply chain challenges following the pandemic on motor vehicle manufacturers are discussed at the end.

Keywords: International supply chain, COVID-19 pandemic, Motor vehicle manufacturing, Time series

1. Introduction

In today's global economy, intricate and interconnected supply chain processes shape the business landscape. The supply chain plays a crucial role due to increasing regional impact, rapid technological advancements, and global progress. Competition has elevated from individual businesses to the industry level, and any disruption affects not only a single business but also the entire sector (Amis et al., 2020). Commercial vehicle manufacturers operating in the passenger transportation sector are grappling with challenges in material sourcing, production processes, and distribution phases. Within the dynamics of international trade, the automotive sector faces an increasingly expanding market. This has led to the rise of global competition and strategic importance in the automotive sector and its main and ancillary industries for both developed and developing countries (Ghassemieh, 2011; Mitchell et al., 2010).

Motor vehicle manufacturers rely on material sourcing to provide the numerous components and parts necessary for vehicle production. These include engines, transmissions, axles, electronic components, body parts, and many other components. Moreover, the automotive sector is a key industry that contributes significantly to economies by generating revenue and employment and by driving technological advancements. International supply chain management is critically important for commercial vehicle manufacturers operating in today's global economy. Thus, ensuring the timely procurement of all components of commercial vehicles enhances production efficiency and strengthens the capacity to respond to customer demands. In this context, supply issues in the automotive sector can have a broad-reaching impact. Global uncertainties such as wars, natural disasters, pandemics, terrorism, and economic crises can lead to international supply issues, which can adversely affect not only vehicle production but also other interconnected industries (Çıkmak & Ungan, 2021; Pişkin, 2017).

In December 2019, the spread of the COVID-19 led to a series of restrictions in the form of the closure of factories and workplaces and imposed limitations on international trade. Automotive components were also affected by these restrictions (LeasePlan, 2020; Sarkis, 2020). Particularly, the Hubei region in China, a critical supply hub for the automotive industry, caused automotive manufacturers worldwide to experience challenges in spare parts supply. This led to a decline in global automotive production, which dropped from 92.5 million units in 2019 to 78 million units in 2020 (KPMG, 2021; Wu et al., 2006).

Disruptions and supply issues in chip and metal sheet production in 2021 (due mainly to the COVID-19 pandemic, the drought in Taiwan, and the Japan earthquake) have led to problems in the production and delivery processes in the global motor vehicle industry. In Türkiye, for example, issues with electronic components supply caused a French car manufacturing company to halt production (Gönültaş et al., 2021). Moreover, in the last decade, issues in container production, shortened product life cycles, intensity of competition, globalisation, and increased raw material and energy prices, along with the unprecedented rise in freight costs, put more pressure on businesses worldwide. In this context, businesses need to adopt effective and industry-specific supply chain management strategies to operate successfully and gain a competitive advantage (Doğan, 2021).

Various risks can lead to various negative consequences for businesses. Ceryno et al. (2015) listed the potential outcomes of risks as sales losses, cost increases, financial losses, decrease in product quality, social losses, threats to customer safety, negative business image or reputation loss, and delays in product deliveries. In a more comprehensive manner, Blackhurst et al. (2005) identified risks in 14 different categories: disruptions/disasters, logistics, supplier dependency, quality, information systems, forecasting, legal regulations, intellectual property, procurement/supply, accounts, inventory, management, capacity, and security. Thus, to be prepared for risks, businesses need to identify these risks and evaluate the cause-and-effect relationships along with their impacts.

In conclusion, the automotive industry, amid intense global demand, heightened risk, and intense competitive conditions, is striving to enhance supply chain performance. To overcome international supply obstacles, commercial vehicle manufacturers have focused on supply chain risk management. However, research and publications in this field have not progressed at the speed required by this industry, especially on the empirical research front. Therefore, there is a need for more empirical research on supply chain risk management in the automotive industry and for developing new models that focus on this sector's specific risks. This study aims to empirically assess the impact of global supply issues on material sourcing, production processes, and logistics management, with a focus on understanding the specific challenges faced by commercial vehicle manufacturers. Identifying risks that affect the supply chain and assessing their potential impacts are critically important. Within this scope, this study specifically addresses delays in material sourcing, disruptions in production processes, and issues in distribution stages, while also examining the impacts of these challenges on sectoral operations.

2. Methodology

Motor vehicle manufacturing typically consists of design and engineering, material preparation, production line assembly, painting and coating, testing and quality control, and packaging and shipping (Çancı & Erdal, 2003). In logistics management, commercial vehicle manufacturers may face transportation challenges at all stages of the supply chain. Thus, properly managing logistics processes plays a critical role in cost savings, customer satisfaction, timely deliveries and business sustainability in motor vehicle manufacturing.

Time series analysis is used in the current study to analyze the data. Time series aims to examine regularly collected data points to identify hidden patterns and trends and to forecast future values based on past data. Time series models are categorized into two main types: stationary (where the time series exhibits symmetric changes in mean and variance and is free from periodic fluctuations) and non-stationary (with either deterministic or stochastic periodic fluctuations). Two main reasons disrupt stationarity. Firstly, the mean of the series may change over time, meaning that the series may contain a deterministic trend. Secondly, the autocorrelations of the series may change over time. Data analysis using time series in the current study, like in other studies, utilizes a set of concepts to facilitate analyzing and interpreting the data over time, including dependency, stationarity, difference transformation, exponential smoothing and curve fitting, and ARIMA (AutoRegressive Integrated Moving Average) (Akdi, 2012).

Data from a large commercial motor vehicle manufacturer in Türkiye were utilized. The study used monthly production quantities of two types of buses, coded as Type A bus and Type B bus, as well as the main cost elements for producing these buses over 15 years. Specifically, data encompassing figures between January 2009 and December 2023 for the following items were used:

• Monthly production volume of the Type A bus (number)

• Monthly production volume of the Type B bus (number)

• Annual increase rate in prices of galvanized stainless-steel sheets (which is usually the most used raw material in terms of input costs in passenger vehicles) in USD (as this commodity is usually globally indexed against USD)

• Annual increase rate in electricity prices in Turkish Lira (TRY) (as this commodity is paid for in TRY)

• Annual increase rate in liquefied natural gas (LNG) prices in TRY (as this commodity is paid for in TRY)

• Annual increase rate in water prices in TRY (as this commodity is paid for in TRY)

• Annual increase rate in labor costs in USD (due to the great fluctuations in labor costs in Türkiye over the same period).

All of the above seven datasets, over 15 years, were obtained from company records. For uniformity purposes (as requested by the company) and to assess increase rates in prices on a single scale (and not prices themselves), the annual increase rates (in percentage terms) of the five cost items (i.e., metal sheets, labor, LNG, electricity, and water prices) were assessed. Then, time series models to represent the monthly production numbers of the two bus types were determined. Monthly production numbers between January 2009 and December 2019 (which is the starting point of the pandemic) for the Type A bus and the Type B bus were used in the current study. Subsequently, using the developed models, forecasts were generated from monthly production numbers of these two buses. Finally, differences between real-life production data and predictions for the period between January 2020 and December 2023 were determined to shed light on the effects of the pandemic.

Moreover, time-series models were assessed using R-squared values, and the Akaike Information Criterion (AIC) was used to compare these models. The model with the minimum AIC value was selected as the best model to represent the data since AIC serves as a penalty, and a lower AIC value generally indicates a better fit for the data (Snipes & Taylorn, 2014). Python was used to analyze the data.

3. Results

Annual increase rates in the prices of galvanized metal sheets and labor costs (equivalent to two minimum wages) are presented in Figure 1. As shown in this figure, a significant surge in price increase rates of galvanized sheets occurred in 2021, followed by a stabilization of prices in 2022 and 2023. This suggests that the effect of the price surge on input costs only gradually diminished from 2022 onwards. Between 2020 and 2022, there seems to be not only a supply problem (as also postulated in the introduction) but also a rise in the prices of essential metal sheets, which are crucial for vehicle production.

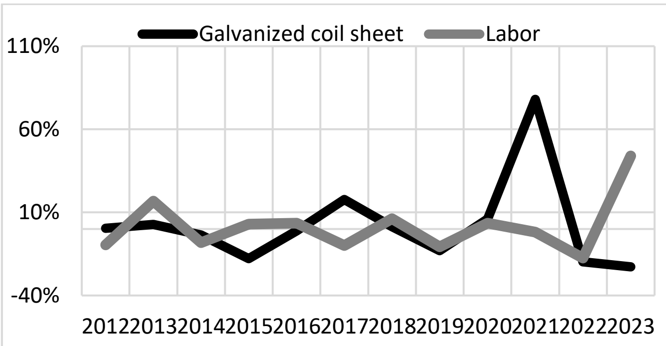

Figure 1. Annual increase rates in metal sheet and labor costs in USD over 12 years

Annual increase rates in gas, electricity, and water prices (all retrieved from company records) are shown in Figure 2. As shown in Figure 2, annual increase rates in gas and water costs rose sharply in 2023. However, the annual increase rate in electricity prices rose sharply to above 65% in 2022, then dropped to around 25% in 2023. As postulated previously, the chip shortage problem that started with the COVID-19 pandemic has negatively affected the production of motor vehicles. The very high increase in energy and raw material costs seen in Figures 1 and 2 after the pandemic clearly exacerbates motor vehicle manufacturers' problems of diminished production volumes caused by this chip shortage, by significantly raising manufacturing costs.

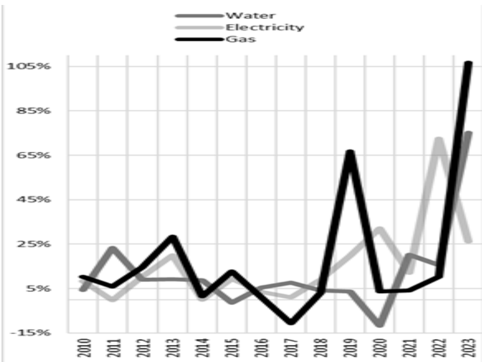

Figure 2. Annual increase rates in gas, electricity and water prices.

Time series statistical metrics for the Type A bus monthly production volume and actual production figures are given in Table 2. According to the AIC penalty scores shown in Table 1, the proposed model, generated through time series analysis in Python, was found to be a typical random walk model. This model is given in Equation 1, where W_t is a white noise series and X_{t-1} is a lagged value of X_t.

$$X_t = X_{t-1} + W_t \tag{1}$$

Table 1. Time series predictions for type A bus production volume.

Model	Intercept	AIC
ARIMA(0,1,0)(0,0,0)[0]	intercept	AIC=1435.233
ARIMA(1,1,0)(0,0,0)[0]	intercept	AIC=1437.164
ARIMA(0,1,1)(0,0,0)[0]	intercept	AIC=1437.140
ARIMA(0,1,0)(0,0,0)[0]		**AIC=1433.235**
ARIMA(0,0,0)(0,0,0)[0]	intercept	AIC=1555.872
ARIMA(1,0,0)(0,0,0)[0]	intercept	AIC=1433.952
ARIMA(0,0,1)(0,0,0)[0]	intercept	AIC=1480.601
ARIMA(0,0,0)(0,0,0)[0]		AIC=1734.954
ARIMA(2,0,0)(0,0,0)[0]	intercept	AIC=1434.764
ARIMA(1,0,1)(0,0,0)[0]	intercept	AIC=1434.798
ARIMA(2,0,1)(0,0,0)[0]	intercept	AIC=1436.770
ARIMA(1,0,0)(0,0,0)[0]		AIC=1444.063

The time series graph for Type A bus production is presented in Figure 3. Specifically, this figure shows the monthly production volume of the Type A bus, as obtained from the manufacturing company's records. By modeling the data presented in Figure 3 in Python, observations that fall outside the 95% confidence interval, along with their prediction differences (2 standard deviations), are considered anomalies and indicated with red dots.

Figure 3 also shows that there are anomalies in both directions and that the production volume remained more or less at a steady state until December 2021. After that, the overall monthly production volume began to increase from the beginning of 2022, with many anomalies observed above the upper band. The differences between the predictions obtained from the time series model for December 2019 onwards and the actual production volumes for both bus types are presented in Table 2. In this table, the prediction error was calculated using Equation 2, where ε is the prediction error, Y is the observation, and $\hat{Y}$ is the prediction.

$$\varepsilon = Y - \hat{Y} \tag{2}$$

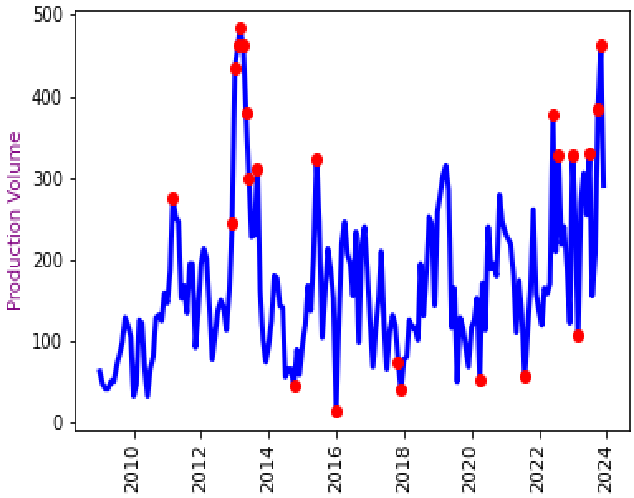

Figure 3. Monthly production volumes of type A bus.

It is clear from Table 2 that the production loss during the pandemic for the Type A bus has not yet been recovered, and the total loss (i.e., the sum of the errors over the 36 post-pandemic months) is estimated to be around 124 vehicles. This can be concluded from the prediction errors given in Table 2.

Table 2. Time series prediction errors of type A vehicle.

Date	ObsA	PredA	ErrorA	ObsB	PredB	ErrorB
Dec-19	69	165	-96	111	227	-116
Jan-20	117	181	-64	180	287	-107
Feb-20	126	191	-65	222	311	-89
Mar-20	153	218	-65	216	352	-136
Apr-20	54	213	-159	54	317	-263
May-20	171	208	-37	198	356	-158
Jun-20	114	197	-83	213	337	-124
Jul-20	240	190	50	273	356	-83
Aug-20	189	171	18	270	297	-27
Sep-20	195	183	12	393	370	23
Oct-20	180	199	-19	339	353	-14
Nov-20	279	207	72	231	345	-114
Dec-20	246	173	73	198	214	-16
Jan-21	234	191	43	120	276	-156
Feb-21	225	198	27	162	302	-140
Mar-21	219	224	-5	162	342	-180
Apr-21	180	220	-40	204	306	-102
May-21	111	215	-104	246	345	-99
Jun-21	174	203	-29	357	325	32
Jul-21	132	197	-65	165	346	-181
Aug-21	57	174	-117	189	286	-97
Sep-21	114	190	-76	201	360	-159
Oct-21	162	208	-46	162	343	-181
Nov-21	261	214	47	84	333	-249
Dec-21	159	179	-20	234	204	30
Jan-22	138	196	-58	312	265	47
Feb-22	120	204	-84	249	291	-42
Mar-22	165	230	-65	360	332	28
Apr-22	159	227	-68	432	295	137
May-22	171	222	-51	375	334	41
Jun-22	378	210	168	450	314	136
Jul-22	210	203	7	228	336	-108
Aug-22	327	178	149	375	275	100
Sep-22	219	197	22	312	351	-39
Oct-22	240	217	23	294	332	-38
Nov-22	189	220	-31	381	321	60
Dec-22	123	185	-62	216	194	22
Jan-23	327	201	126	459	254	205
Feb-23	246	210	36	486	279	207
Mar-23	108	236	-128	528	322	206
Apr-23	270	234	36	417	284	133
May-23	306	229	77	546	322	224
Jun-23	255	216	39	414	302	112
Jul-23	330	209	121	561	326	235
Aug-23	156	182	-26	309	264	45
Sep-23	207	203	4	537	341	196
Oct-23	384	225	159	402	322	80
Nov-23	462	227	235	402	309	93

Time series statistical metrics for the Type B bus monthly production volume are given in Table 3, and the actual production figures are given in Table 2. According to the AIC penalty scores shown in Table 3, the proposed model generated through time series analysis is a typical first-order moving average model (Chatfield, 1996). This model is given in Equation 3, where $\boldsymbol{\nabla X_t}$ represents the first difference of the variable at time t, calculated as $\boldsymbol{X_t - X_{t-1}}$. This term signifies the rate of change of the variable over time. The coefficient $\boldsymbol{\theta}$ is associated with the moving average (MA) component and quantifies the impact of the previous period's white noise on the current change. $\boldsymbol{W_{t-1}}$ denotes the white noise term from the preceding period, representing unexplained random variations in the model. W_t, on the other hand, is the white noise term in the current time period.

$$\nabla X_t = \theta W_{t-1} + W_t \tag{3}$$

Table 3. Time series predictions for type B bus production volume.

Model	Intercept	AIC
ARIMA(0,1,0)(0,0,0)[0]	intercept	AIC=1751.681
ARIMA(1,1,0)(0,0,0)[0]	intercept	AIC=1720.142
ARIMA(0,1,1)(0,0,0)[0]	intercept	AIC=1714.374
ARIMA(0,1,0)(0,0,0)[0]		AIC=1749.682
ARIMA(1,1,1)(0,0,0)[0]	intercept	AIC=1715.303
ARIMA(0,1,2)(0,0,0)[0]	intercept	AIC=1715.904
ARIMA(1,1,2)(0,0,0)[0]	intercept	AIC=1716.762
ARIMA(0,1,1)(0,0,0)[0]		**AIC=1712.376**
ARIMA(1,1,1)(0,0,0)[0]		AIC=1713.307
ARIMA(0,1,2)(0,0,0)[0]		AIC=1713.907
ARIMA(1,1,0)(0,0,0)[0]		AIC=1718.145
ARIMA(1,1,2)(0,0,0)[0]		AIC=1714.765

The time series graph showing monthly production volume of the Type B bus is presented in Figure 4. By modeling the data presented in Figure 4 in Python, observations that fall outside the 95% confidence interval, along with their prediction differences (2 standard deviations), were considered anomalies and indicated with red dots.

Figure 4 shows an obvious decreasing trend of anomalies, occuring only below the lower band between 2020 and 2024, with no anomalies ever recorded above the upper band. This indicates that production volumes were below expectations between 2020 and 2024. The differences between the predictions obtained from the time series model for December 2019 onwards and the actual production volumes for the Type B bus are presented in Table 2.

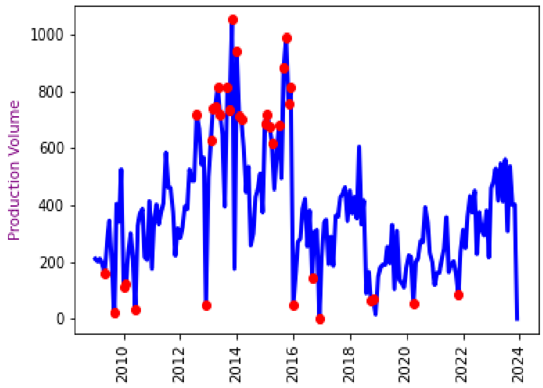

Figure 4. Monthly production volumes of type B bus.

It is clear from Table 2 that the production loss during the pandemic for the Type B bus has not yet been recovered. Similarly, the total loss (i.e., the sum of the errors over the 36 months) is estimated to be around 626 vehicles, as can also be concluded from the prediction errors given in Table 2.

Overall, the results show that supply chain problems caused by the COVID-19 pandemic, and the subsequent shortage in chip production, negatively affected the production of buses. It was also observed that this problem persisted until 2024 and has not been resolved.

4. Conclusions

Time series analysis conducted for the Type A and type B buses revealed that the production loss following the pandemic has still not been fully compensated. In particular, as can be seen in Table 2, the total production loss over the 36 months is approximately 124 vehicles for the Type A and 626 vehicles for the Type B bus. Therefore, it can be concluded that this corresponds to a loss of approximately one month's production for the Type A bus and approximately two months's production for the Type B bus over the 36-month period. These results, based on time series analysis, provide valuable insights for commercial vehicle manufacturers on how to cope with supply issues and cost increases.

Overall, the increase in energy and raw material costs, in addition to the chip shortage, was observed to affect production volumes and raise the production costs of the buses in question after the pandemic. This study provides important insights for commercial vehicle manufacturers, assisting them in making strategic decisions, particularly in supply chain management and cost planning. Extending similar analyses to other industries in future research is also expected to contribute to a better understanding of general trends in this field.

One limitation of this research was the breadth of the analysis performed on the company's dataset. Due to commercial confidentiality and strategic risks, the company, understandably, was not willing to share more data about the production process, which is a common feature of empirical studies similar to this one. Another limitation is that this study is specific to the Turkish motor vehicle manufacturing sector. Although similar manufacturers in other countries are expected to have faced similar problems due to the COVID-19 pandemic, generalizing the results to them requires more empirical research in this area.

Declarations

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