POST-PANDEMIC ROAD ACCIDENT ANALYSIS: PATTERNS AND IMPACTS

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Abstract: This study analyzes the impact of COVID-19 restrictions on road accident trends in the Czech Republic from 2015 to 2024, utilizing a comprehensive dataset of over one million recorded accidents. The research highlights a significant decline in accident rates during the strict lockdown periods, correlating reduced mobility with fewer traffic incidents. As restrictions eased, accident rates rose again, revealing seasonal variations and regional disparities, particularly in urban areas like Prague. Findings suggest that the pandemic has reshaped commuting patterns and could influence future traffic management strategies. The analysis underscores the need for targeted policies to enhance road safety, especially during high-risk seasons.

Key words: *COVID-19, road accidents, traffic safety, lockdown effects, urban mobility, seasonal trends, data analysis, ARIMA*

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1. Introduction

The COVID-19 originated in China, has impacted to global economy significantly [1]. Numerous sectors of the economy, financial markets, and government elections were affected by it [2]. As of November 2024 the number of confirmed cases stands on 776,618,091, confirmed death cases reaching 7,071,324 [1]. Countries have tried to reduce the spread of the virus across the population. Common restrictions are wearing masks, minimal distance between people, supporting companies to move employees from home, encouraging online education, prohibiting travelling not only to other countries but also within the country. In most countries lockdown was a critical reaction to stopping spreading the virus, despite decreasing demand in many sectors of economy such as travel, hospitality, and restaurants [3], other sectors saw dramatically growth, such as online shopping, payment by bank card [4]. Also, pandemic COVID-19 is a catalysator for digitalization of the economy, in other words companies strategies were changed and digitalization reduce operation costs, reduce labor intense [5].

Regarding lockdown universities moving classes to different on-line platforms (Zoom, Google, Microsoft Teams etc.), it reflects additional investment to software,

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hardware. Virtual classroom is an advantage for people with disabilities, by providing a more flexible and accessible model of education. The concept of distance learning was introduced in 1970s and has historically shown a positive correlation with development internet across the world. The exponential grow distance education shows in the period 2020–2021, where first lockdowns were applied [6]. This rapid increase highlighted the potential of online education to reach diverse student populations regardless of geographic or physical limitations. As educational institutions adapted to distant learning, many invested in digital accessibility features and tools that supported a wider range of learning needs. This period of accelerated digital adoption is likely to leave a lasting impact on the educational landscape, where a hybrid or fully remote model may become a permanent option for students across the globe.

Also, COVID-19 interrupts global supply-chain of fast moving consumer goods (FCMG) and delivery spare parts in automative industry. For FCMG mainly raw materials are imported from China, where was an epicentrum of COVID-19, state Wuhan. This was broken, mostly supply-chains and manufacturers had a shortage of raw materials. Another negative impact to manufacturing is as social distance, create defensive workplaces against spread the virus. Automative industry is a major part of the European economic sector. The European car production dropped down by 23.5 percent in the 2020 [7], during first 5 months of 2020 commercial vehicle registration dropped by 44.4% [8], which had impact not only manufacturers but also householder incoming. The Czech Republic is a global player in the European automative industry, during the 2019 were manufactured 1,427,563 pcs cars and LUV, but in the 2020 only 1,152,901 pcs, it is 19.2% smaller than previous year [9].

The first COVID-19 case in the Czech Republic was reported on 1st March 2020, and at the end of 11 March the total cases was 63 [10]. The spread of the virus across the population was extremely high and on 12th March the Czech Republic declared a state of emergency [11]. During the COVID-19 pandemic, the Czech Republic implemented several lockdowns with stringent measures to control the virus's spread. The first lockdown began on March 16, 2020, lasting until May 25, 2020 [14].

During this period, borders with Germany, Austria, Slovakia, and Poland were closed, while schools, universities, and non-essential businesses were also shut down to minimize movement and gatherings. As cases surged again in the autumn, the second lockdown was introduced on October 21, 2020 [12], lasting until November 20, 2020. This lockdown brought back strict restrictions, including the closure of non-essential businesses and schools, alongside limits on gatherings. Rising infection rates led to a third lockdown starting on December 27, 2020 [13], which extended through April 12, 2021. This period saw a reintroduction of strict measures, with schools and non-essential services closed and travel restricted between districts. The gradual easing began on April 12, allowing a partial reopening of schools and some non-essential businesses as the infection rate stabilized.

The Czech Republic has population 10,900,555 habitants as of January 1, 2024 [14] and divided by 14 regions, has a regional distribution that varies widely in population density and proportional population share (see Tab. I). Prague, the capital city, represents 12.7% of the population, with a high density of 2,790 people

per square kilometre, the most densely populated in the country. Other regions, such as Central Bohemia, South Moravia, Usti nad Labem, also have significant populations but with lower population densities compared to Prague.

Region	Population	Proportional Population [%]	Density [people/km^2]
Capital city of Prague	1,384,732	12.7	2,790.0
Central Bohemia	1,455,940	13.4	133.0
South Bohemia	654,505	6.0	65.1
Plzen	613,374	5.6	80.2
Karlovy Vary	295,077	2.7	89.1
Usti nad Labem	811,169	7.4	152.0
Liberec	450,728	4.1	142.0
Hradec Kralove	555,949	5.1	117.0
Pardubice	530,560	4.8	117.0
Vysocina region	517,960	4.7	76.2
South Moravia	1,226,749	11.3	171.0
Olomouc	632,864	5.8	120.0
Moravian-Silesian	1,189,204	10.9	219.0
Zlin	580,744	5.3	147.0

Tab. I *Demography of Czech regions – total population and proportional representation in the Czech Republic (as of January 1, 2024).*

The primary motivation for this analysis is to understand how large-scale disruptions in human mobility can influence accident trends and inform future policy decisions for improving road safety in both crisis and non-crisis situations. By examining these trends, I aim to help anticipate and mitigate the risks associated with fluctuating traffic volumes, seasonal variations, and future global disruptions.

2. Methodology and Data

The dataset comprises 877,060 road accidents across the Czech Republic since 2015 [15]. The dataset is stored in a SQL database, which is a more powerful instrument for cleaning, analysis and working with data. For each accident, information is available on the following:

1. Date
2. Time
3. Place (GPS coordinates in the WGS84 geographic coordinate system)

The source of the data is a database of the Police of the Czech Republic, and for small accidents drivers can fulfil the Incident Assessment Report. However, there

are obligations to report to the police in certain cases [19, 20], and the data set doesn't cover all accidents during the study period.

In the accident dataset, the time component is represented by the year, month, and time. However, in some cases, there may be situations where the time is unknown, or the exact minutes are not specified.

In the data set, the time component is represented in Tab. II. In cases where "Time unknown" is noted, it cannot be determined whether the accident occurred at the reported location, in other words, the accident may have occurred at a different location and on a different day or month. In this paper, all accidents for which the time is unknown have been excluded.

Classification	Count	Proportion (%)
Full time and date	740888	84.4
Time unknown	103501	11.8
Missing minutes	32671	3.7

Tab. II *Number of road accidents in the Czech Republic by established classification (January 1, 2015 – August 31, 2024).*

The graph (Fig. 1) displays a detailed analysis of traffic accident rates across various regions of the Czech Republic, adjusted for population size monitored monthly from January 1, 2015, to August 31, 2024 [18]. This temporal and spatial examination provides insight into how both seasonal changes and the COVID-19 pandemic-related lockdowns influenced traffic patterns and accident rates, revealing the impact of social restrictions on mobility. Same pattern was founded in the previous studies: the USA [19], Italy [20, 21], Spain [22], Peru [23], Greece and Kingdom of Saudi Arabia [24], otherwise number of accidents was increased among meal food delivery riders by motorcycles in Thailand [25], Malaysia [26].

Each panel in the graph represents a different administrative region within the Czech Republic, with monthly accident rates per people/km^2 plotted on the y-axis. The x-axis covers a uniform timeline for all regions, allowing for an easy comparison across time and location. The analysis also incorporates color-coded vertical bands that delineate key pandemic-related periods:

– First lockdown (red): Encompassing the initial, stricter restrictions imposed in early 2020.

– Second lockdown (orange): Marking the reintroduction of restrictions in response to the second wave of COVID-19 in late 2020.

– Third lockdown (green): Last lockdown in the Czech Republic.

These coloured bands serve as markers to observe correlations between lockdown intensity and accident rates, providing a quasi-experimental approach to understanding how varying levels of mobility influence accident incidence.

Fig. 1 *Road accidents in the Czech Republic by region (January 1, 2015 – August 31, 2024).*

3. Impact of Lockdowns on Accident Rates

Across most regions, the initial lockdown (red band, Fig. 1) is associated with a pronounced drop in accident rates. This decline can be attributed to reduced traffic volume, as strict restrictions limited non-essential travel and significantly lowered daily commuter numbers. The reduction in accidents during this phase suggests a direct correlation between mobility restrictions and traffic incidents. This pattern is most influential for high density areas: capital city of Prague and Central Bohemia region.

Following the initial lockdown, the summer easing phase from March 1, 2020, to May 1, 2020, coincided with an uptick in accident rates across regions. As restrictions were lifted, travel resumed, contributing to increased traffic density and,

consequently, higher accident rates. The subsequent second lockdown (yellow band, Fig. 1) reveals a similar, though sometimes less steep, decrease in accidents, indicating that while restrictions still reduced mobility, the public may have adjusted travel behaviours compared to the first lockdown phase.

Beyond the lockdown periods, seasonal trends are discernible across regions. Accident rates generally peak during the winter months, likely due to challenging driving conditions associated with snow, ice, and reduced daylight. For example, peaks around January and February are visible across several years in various regions, reflecting the influence of seasonal weather patterns on road safety.

Moreover, there is notable regional variation in accident rates. Urban and densely populated regions, such as Prague and Central Bohemia, tend to exhibit consistently higher accident rates. This pattern likely reflects increased vehicle density and urban traffic complexity, which elevates the risk of collisions. Conversely, more rural regions like Karlovy Vary and Vysocina Region maintain relatively low and stable accident rates. This disparity highlights how population density and urban infrastructure contribute to regional differences in accident incidence.

A less pronounced decrease in accident rates during the second lockdown (orange band, Fig. 1) suggests a potential adaptation in mobility patterns. By late 2020, individuals and businesses may have adapted to restrictions by adopting modified commuting patterns, such as staggered working hours, increased local travel, or more reliance on personal vehicles over public transportation. This adaptation may explain why the reduction in accidents is not as sharp in the second lockdown compared to the first.

Also, during the third lockdown (green band, Fig. 1), the number of road accidents is notably lower compared to the same summer season period in previous years.

4. Trend in Prague

The capital city Prague has higher density population across Czech Republic, respectively 2,790.0 people/km^2 and 137.9 people/km^2 at the January 1, 2024, and accidents decreasing since 2020 or after first lockdown can be seen on Fig. 1.

Fig. 2 shows number of accidents across year and month in Prague. The data are presented in the heatmap, where each cell corresponds to a specific month and year. The amount of accidents is represented by colour intensity, ranging from light blue (fewer accidents) to dark blue (more accidents), with values annotated for precise analysis. The data spans 2015 to 2024, capturing a full decade of monthly totals, where the peak of accidents in 2018–2019, after 2020 can been seen that trend is decreasing.

The series exhibits strong seasonal patterns, with noticeable peaks and low points reflecting variations in monthly accidents count. Peaks are generally observed in the May-June and October-November, aligning with high accident seasons such as summer, while troughs are visible in July and January. The original data also shows an overall growth trend from 2015 to 2019, followed by a significant decline starting in 2020, likely due to the impact of the COVID-19 pandemic. The pandemic led to a decrease in the number of road accidents, primarily due to reduced traffic volumes from lockdowns and restrictions. While there may have been

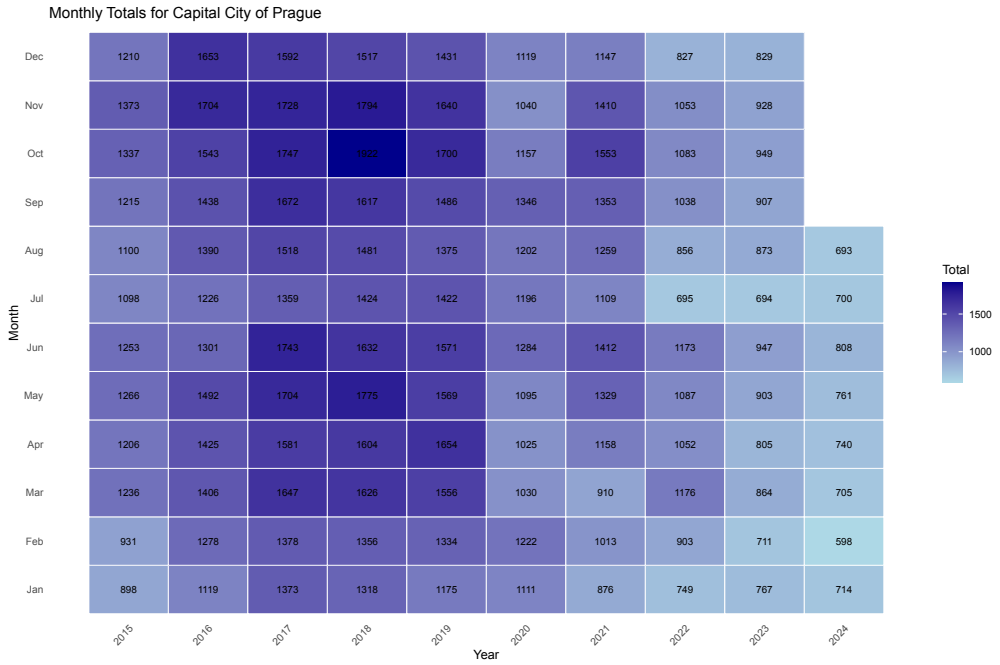

Fig. 2 *Monthly distribution of road accidents across years in Prague (01.01.2015 – 31.08.2024).*

changes in driving behavior during this period, such as fewer long-distance trips, the main factor contributing to the drop in accidents was the significant reduction in traffic. After the easing of restrictions, accident rates began to recover, though they have not yet returned to pre-pandemic levels.

For trend component estimate was used X-12 ARIMA of the US Census Bureau (Fig. 3) [27]. The model X-12-ARIMA or $ARIMA(1,1,1)(0,1,1)_{12}$:

$$(1-\phi_1 B)(1-B)(1-B^{12})Y_t = (1-\theta_1 B)(1-\Theta_1 B^{12})e_t, \tag{1}$$

where

$(1-B)$ – represents first-order differencing,
$(1-B^{12})$ – the seasonal differencing,
$(1-\theta_1 B)$ – moving average for the non-seasonal component,
$(1-\phi_1 B)$ – autoregressive terms for the non-seasonal component,
$(1-\Theta_1 B)$ – moving average for the seasonal component,
e_t – represents the white noise error term at time t.

The left-down plot on Fig. 3 isolates the trend component extracted by X-12-ARIMA. This green line provides a clearer view of the long-term trend without the noise of seasonal fluctuations. The trend line confirms that accidents count grew consistently from 2015 to 2019, peaking in 2018–2019. The significant dip in 2020 corresponds to the pandemic's impact, with the trend declining steeply. A recovery is observed post-2021, though the trend remains lower than in the peak

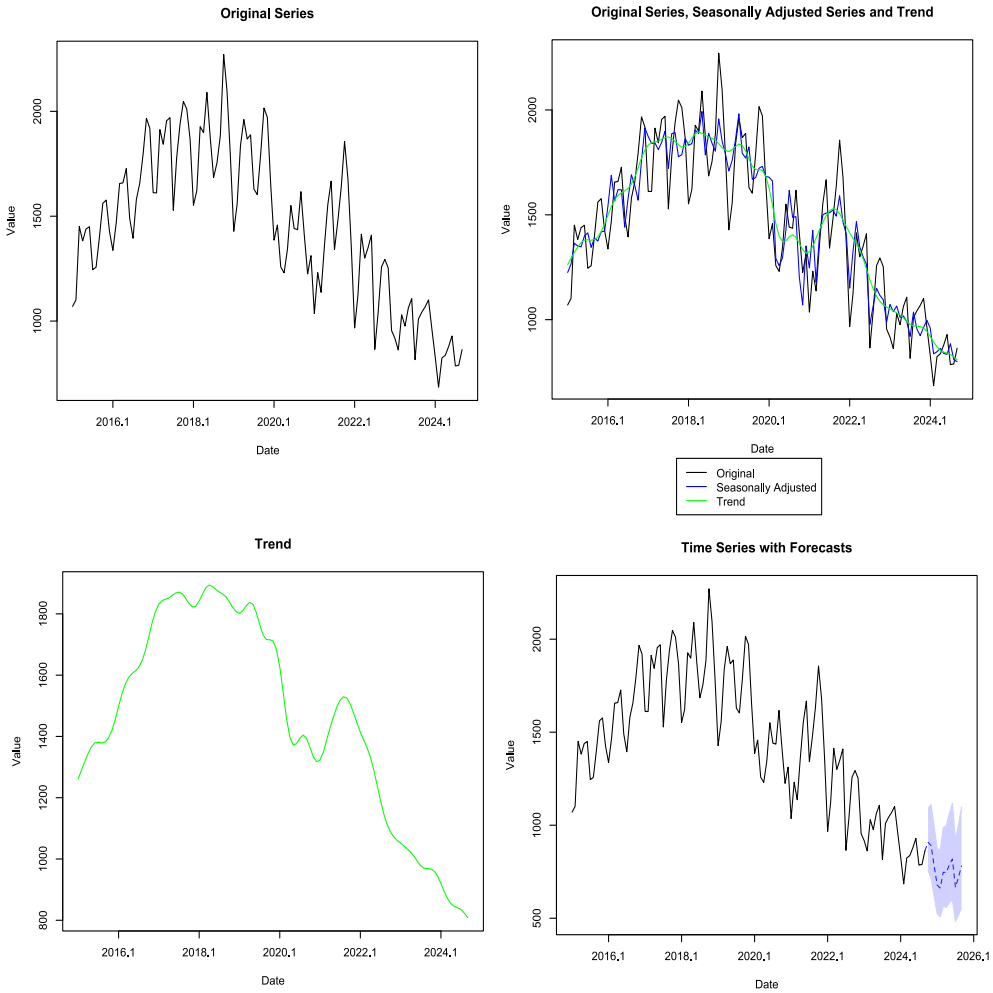

Fig. 3 *X-12-ARIMA plots: Time series of road accidents in Prague (01.01.2025 – 31.08.2024), seasonality-adjusted series, trend, forecast with confidence interval 95% (CI).*

years before the pandemic, indicating a lingering effect on accidents in Prague city. The Fig. 3 also includes forecasts from the seasonally adjusted data, showing projected count of road accidents from early 2024 onward, with a 95% confidence interval. Confidence Interval (Shaded Area): The blue shaded area around the forecast line indicates the 95% confidence interval, providing a range within which future values are likely to fall.

The forecast suggests that count of road accidents in Prague, Czech Republic are expected to remain relatively stable with some potential for slow growth (Tab. III), though uncertainty increases over time as shown by the widening confidence intervals. The forecasted values indicate that road accidents numbers are unlikely to return to the high levels seen in 2018–2019 within the short term. This

highlights a cautious outlook for recovery, potentially influenced by residual effects of the pandemic, and remote work.

Date	Forecast	Standard error
2024 Sep	813.0	110.9
2024 Oct	914.0	134.7
2024 Nov	876.0	148.8
2024 Dec	726.5	159.6
2025 Jan	495.4	169.1
2025 Feb	547.4	177.8
2025 Mar	683.5	186.0
2025 Apr	692.5	193.8
2025 May	764.0	201.3
2025 Jun	785.3	208.6
2025 Jul	562.7	215.6
2025 Aug	645.8	222.3

Tab. III *Forecast of road accidents and standard error in Prague, Czech Republic (September 2024 – August 2025).*

5. Discussion

The findings from this data visualization align with broader research on how pandemic-related restrictions influence urban mobility and accident trends. Reduced accident rates during lockdown periods are consistent with studies demonstrating that decreased mobility leads to fewer traffic-related incidents. This correlation emphasizes the extent to which traffic accidents are influenced by social behavior and mobility intensity, suggesting that targeted policies can effectively manage road safety during emergencies.

Furthermore, the regional and seasonal variations observed in accident rates underscore the importance of contextual factors in transportation safety policy. For instance, urban regions with higher baseline accident rates may benefit from interventions that manage congestion and improve infrastructure, particularly during high-risk winter months. Meanwhile, the clear seasonal peaks indicate that additional resources for road safety, such as winter road maintenance, could be allocated in anticipation of these high-risk periods.

The greatest impact of COVID-19 is seen in the capital city of the Czech Republic, Prague, because it was mainly affected in pandemic, and mostly employers turn business model to remote work. During COVID-19 pandemic, the office occupancy rate in Prague was 28%, but at the time writing, it is 61% [28]. As was shown, the lockdowns had influence on numbers of road accidents in the country, and most affected capital city Prague, the turnback for employees work on site can change the trend, and as a result the situation rapidly returned to pre-pandemic levels.

As the world transitions into a post-pandemic era, it is essential for policymakers and urban planners to recognize the lasting changes in commuting habits and to adapt road safety initiatives accordingly. Future research should explore the long-term implications of remote work on traffic patterns and investigate how adaptive traffic management can be optimized in response to evolving mobility trends.

In addition to the changes in commuting habits, the timing of the lockdowns played a significant role in shaping the patterns of accidents. The first lockdown in spring 2020 coincided with milder weather conditions, which likely contributed to a reduction in accident rates due to fewer vehicles on the road. However, the third lockdown, which took place in winter 2020–2021, introduced a different set of circumstances. The winter months, with their associated weather challenges such as snow, ice, and reduced daylight hours, likely contributed to a different accident pattern, even though traffic volumes were low. This seasonal difference underscores the need for tailored road safety interventions that account not only for mobility changes but also for environmental factors that increase the risk of accidents.

Furthermore, regional variations in accident rates provide important insights into how different areas responded to lockdown restrictions. Urban regions, like Prague, which typically experience higher traffic volumes and accident rates, saw a sharper decline in accidents during lockdowns. However, rural regions, with less intensive traffic flow, might have experienced a less pronounced effect. This suggests that region-specific interventions such as congestion management in cities or infrastructure improvement in rural areas could play a crucial role in reducing accidents across various geographic contexts

6. Conclusion

This study provides valuable insights into the interplay between social restrictions, regional characteristics, and road accident trends. The findings demonstrate that lockdowns significantly reduced mobility and, consequently, accident rates, while the relaxation of restrictions led to predictable rebounds. Seasonal and regional patterns further highlight the impact of environmental and demographic factors on road safety. Policymakers can leverage these insights to develop targeted interventions that enhance road safety during crises and regular seasonal fluctuations. Additionally, promoting remote work, particularly in urban areas like Prague, could contribute to sustaining lower accident rates and integrating traffic management into broader public health strategies.

However, this study is based on reports from the Czech police and does not cover all road accidents across the country, as certain incidents, particularly minor ones, were excluded from the dataset. Therefore, the results may not fully represent the total scope of accidents in the Czech Republic. Future research could consider incorporating additional data sources, such as reports from insurance companies, to provide a more comprehensive understanding of the relationship between social restrictions and road safety.

Also, accidents where the time was unknown were excluded from the dataset. The lack of accurate timing data made it impossible to determine when and where the accidents occurred, which could affect the reliability and interpretation of the results. This exclusion was necessary to ensure the validity of the analysis, as the

timing of accidents is crucial in understanding patterns and trends over time. As a result, the dataset used in this study may not fully represent all accidents that occurred during the study period.

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