Impact of Time of Day on Traffic Accident Fatalities

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Abstract

Traffic accidents are one of the greatest public safety concerns in the world and are the most common cause of death worldwide. This paper attempts to analyze microdata from the ISTAT dataset to explore the causal relationship between time of day (day vs night) and traffic fatality rates in Italy. Using logistic regression with clustered standard errors, advanced propensity score techniques, including Inverse Probability Weighting (IPW) and Propensity Score Matching (PSM), were employed to estimate the Average Treatment Effect on the Treated (ATT) to control for selection bias. The results indicate that accidents at night are 1-1.25% more likely to result in fatalities compared to daytime accidents. Furthermore, the study has proven the importance of regional and temporal variations in fatal accidents, emphasizing the necessity for targeted nighttime interventions. These insights provide a robust foundation for developing evidence-based policies aimed at enhancing road safety through measures such as infrastructure investments and age-based programs.

1 Introduction

Traffic accidents are one of the major threats to public safety, with yearly estimates of at least 1.3 million deaths and millions of injuries, according to the World Health Organization.[1] Reducing traffic accident risks remains a critical research priority. This study assesses the causal relationship between the time of day (day vs. night) and fatality rates in car crashes. By using the ISTAT "Survey on Road Accidents

[1] World Health Organization, *Global Status Report on Road Safety* ,

Resulting in Death or Injury" microdata, the study aims to reveal whether accidents occurring during the day are less severe compared to those at night across various Italian provinces. Italy's highly diverse weather conditions and unique geographical features provide a compelling context for studying these effects. Our findings are expected to offer valuable insights for policymakers, enabling the design of targeted, data-driven interventions to reduce traffic fatalities such as localized interventions.

2 State of the Art

The relationship between the time of day and the severity of traffic accidents has been one of the most widely explored aspects in transportation safety research. There is a clear distinction between daytime and nighttime accidents, with evidence that nighttime accidents often result in higher fatality rates due to a combination of environmental and behavioral factors.

2.1 Nighttime Traffic Accidents and Fatalities

The number of traffic accidents and fatalities that occur at night compared to daylight accidents, nighttime accidents are more dangerous and have a higher chance of becoming fatal. Numerous studies have demonstrated that the chance of deadly nighttime crashes is much increased when there is less visibility and more cases of drunk driving.[2] For example, a significant portion of nighttime fatalities are caused by drunk drivers, and alcohol-related crashes are more frequent at night.[3] The absence of sunlight and daylight slows down reaction times, making it more challenging for drivers to avoid unforeseen dangers.

Another significant factor that contributes to the fatality of accidents that occur at night is fatigue. Due to the effects of circadian rhythm, drivers who operate vehicles late at night tend to be less attentive, which results in shorter reaction times and a higher risk of catastrophic errors.[4]

2.2 Daytime Accidents: Frequency Over Severity

In contrast, daytime accidents occur more frequently but typically result in fewer fatalities. Daytime accidents are frequently caused by increased traffic and population, which slows down cars on average but increases the likelihood of crashes. Daytime accidents typically have lower speeds, fewer fatalities, and

[2] Taylor, J. F., & Newstead, S. "Accident risk and severity at night." *Accident Analysis & Prevention*, 31, 93–104, 1999.

[3] Rosenbloom, T., & Eldror, E. "Fatal crashes and alcohol-impaired driving." *Transportation Research Part F: Traffic Psychology and Behaviour*, 13(3), 189–194, 2010.

[4] Stutts, J. C., Wilkins, J. W., & Vaughn, B. V. "Driver risk factors for sleep-related crashes." *Accident Analysis & Prevention*, 35(3), 321–331, 2003.

less major injuries.[5] Because it is easier to see and there are more emergency services available during the day, survival rates are also greater.

However, there are challenges associated with accidents that occur during the day. The frequency of daytime accidents is significantly influenced by driver distraction, which is frequently brought on by multitasking or using a cell phone.[6] Despite increasing the incidence of accidents, these factors are less likely to result in fatalities than the behavioral risks that are more common at night.

2.3 Causal Inference in Traffic Safety Research

Traffic safety research has increasingly turned to causal inference methods to better understand the relationship between time of day and accident outcomes. Propensity score matching (PSM) and inverse probability weighting (IPW) have become an important approach to addressing confounding variables, such as road conditions, weather, and driver demographics.[7] Both methods are designed to reduce bias in estimating treatment effects by creating comparable groups or adjusting for differences in baseline covariates.

For example, propensity score matching (PSM) revealed that nighttime accidents are 40% more likely to result in fatalities compared to their daytime counterparts, even after adjusting for confounders.[8] Similarly, inverse probability weighting (IPW) demonstrates that night driving substantially increases the risk of fatal outcomes, particularly in rural areas where access to emergency services is limited.[9]

2.4 Gaps in Existing Literature

Despite the wealth of descriptive analyses, significant gaps remain in the causal understanding of how time of day influences accident outcomes. Many studies rely on aggregated or regional data, which can mask critical nuances. Furthermore, the interaction between nighttime driving conditions (e.g., lighting, and weather) and behavioral factors (e.g., fatigue, and alcohol use) has not been sufficiently explored in a causal framework. This study aims to address these gaps by using microdata from ISTAT to evaluate the

[5] Elvik, R. "The relationship between speed and road safety: A review of the literature." *Transport Reviews*, 24(6), 659–671, 2004.

[6] Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. "The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data." *National Highway Traffic Safety Administration Technical Report*, 2006.

[7] Rosenbaum, P. R., & Rubin, D. B. "The central role of the propensity score in observational studies for causal effects." *Biometrika*, 70(1), 41–55, 1983.

[8] Qin, X., & Ivan, J. "Crash analysis using propensity score methods." *Journal of Safety Research*, 35(4), 453–460, 2004.

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direct causal effect of time of day on traffic accident fatalities. By leveraging propensity score methods and rich covariate data, this research contributes to a deeper understanding of the unique risks associated with nighttime driving and offers actionable insights for policymakers.

3 Data and Methodology

3.1 Data Sources

The dataset used in this analysis originates from the ISTAT "Survey on Road Accidents Resulting in Death or Injury: Public Use Microdata". This dataset includes specific information about car accidents that happened in Italy, with variables describing accident characteristics, vehicle attributes, and driver demographics.

The original dataset was preprocessed to focus on accidents occurring within Italy, ensuring sufficient variation across the regions. The variables related to deaths, accident conditions, and driver demographics were chosen based on their relevance to the casual analysis. The dataset needed extensive preprocessing before it could be used, to ensure accuracy and relevance.

3.2 Data Cleaning and Preprocessing

Records with inconsistent or missing values were not included. Only information from the top 25 provinces with the most accidents was kept. After considering the accident and fatality rates in other cities, we decided to exclude them from the analysis for reliability. Non-numeric and missing values were found in the `Ora` column; they were eliminated. Similarly, in order to concentrate on legitimate and comprehensible age ranges (e.g., `18-29`, `30-44`), irrelevant categories like `0-5` and `6-9` were removed from the `veicolo__a__et__conducente` column. Only important factors have been incorporated into the model to improve comprehension of causality; while others were purposefully excluded. During the preprocessing stage, the "Ora" variable was converted into a binary variable. Additionally, other categorical variables were transformed into dummy variables to be used in the logistic regression analysis.

3.3 Key Variables

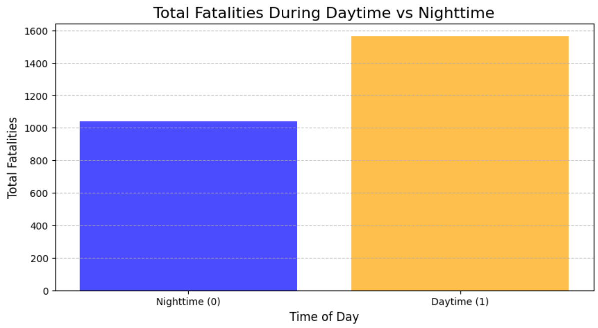
The following variables were included in the analysis based on their significance in predicting the likelihood of accidents during the day versus night:

- **Day/Night Indicator (day_night):** Binary variable indicating whether the accident occurred during daytime (7 AM to 7 PM, coded as 1) or nighttime (coded as 0).
- **Province Indicators:** Dummy variables for the top 25 provinces, including *Genova, Roma, Napoli, Firenze, Milano*, etc., based on the highest accident counts.
- **Driver Age (veicolo__a__et__conducente):** Categorical variable capturing the driver's age group (18-29, 30-44, 45-54, 55-64, 65+).
- **Road Type (tipo_di_strada):** Categorical variable describing the road type (e.g., highways, rural roads, or urban roads).
- **Weather Conditions (condizioni_meteorologiche):** Categorical variable capturing weather during the accident (e.g., clear, rain, fog).
- **Pavement Conditions (pavimentazione):** Categorical variable indicating road surface conditions (e.g., dry, wet, icy).
- **Intersection Type (intersezione_o_non_interse3):** Indicator of whether the accident occurred at an intersection (e.g., roundabout, T-junction).
- **Signage (segnaletica):** Categorical variable indicating the presence and type of traffic signs or signals (e.g., stop sign, traffic light, no signage).

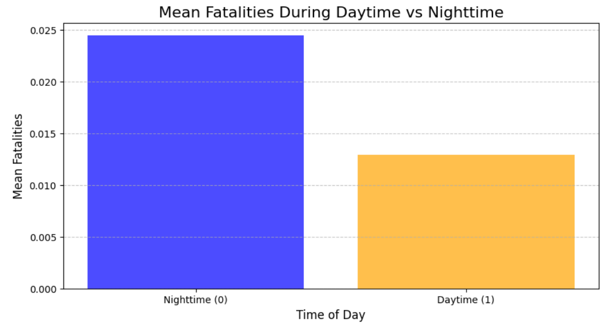
All categorical variables were encoded as dummy variables to facilitate regression and propensity score estimation.

3.4 Comments on the Data

The descriptive statistics reveal notable differences between daytime and nighttime accidents. Nighttime accidents have a higher proportion of fatalities (*morti_entro_24_ore*), consistent with literature suggesting increased severity due to impaired visibility and higher rates of risky behaviors such as alcohol consumption. In contrast, daytime accidents occur more frequently on urban roads and intersections, potentially reflecting higher traffic density during working hours.



(a) Total Day vs Night



(b) Mean Day vs Night

Figure 1: Comparison of Total and Mean Day vs Night

4 Identification of Causal Effects

4.1 Challenges in Identifying Causal Effects

There are various difficulties in determining the causal relationship between the time of day and traffic accident fatalities. The main problem is the existence of confounding factors that affect the frequency and severity of accidents at the same time. For instance:

- **Driver Speed:** As a possible confounder variable, elevated vehicle speeds, which are often seen at night due to less traffic congestion and decreased enforcement of traffic laws, can systematically affect the relationship between accident results and time of day.
- **Driver Characteristics:** The observed effect may be skewed by behavioral and demographic differences among drivers, such as fatigue at night or distraction during the day.
- **Emergency Response Time:** The relationship between the time of day and accident outcomes can be ambiguous by longer emergency response times at night, which could increase the chance of fatalities compared to daylight, due to decreased service availability or slower access to healthcare.

It is challenging to directly compare the outcomes of accidents at night and during the day without considering both observable and unobservable variations influenced by these variables

4.2 Adopted Strategy

To address these challenges, we adopt a **propensity score-based causal inference framework**, which includes two complementary approaches:

1. **Propensity Score Matching (PSM):** We estimated propensity scores using logistic regression, where the treatment variable is *day_time* (1 for daytime, 0 for nighttime). The covariates included road, weather, and driver characteristics. Treated (daytime) and control (nighttime) observations were matched based on their propensity scores, ensuring that matched pairs are comparable across covariates.

2. **Inverse Probability Weighting (IPW):** We employed IPW to reweight the sample, creating a pseudo-population in which the distribution of covariates is balanced and independent of treatment assignment. This method provides unbiased estimates of the Average Treatment Effect on Treated (ATT).

4.3 Rationale for the Strategy

This strategy is reasonable for the following reasons:

- **Balancing Confounders:** Propensity score methods effectively balance observed covariates between treated and control groups, reducing bias due to observable confounders.

- **Flexibility:** Both PSM and IPW allow for the inclusion of multiple covariates, addressing the multidimensional nature of confounding in traffic accident data. IPW, in particular, provides greater flexibility in weighting observations.

- **Robustness:** By combining matching and weighting, the analysis leverages the strengths of both approaches, increasing confidence in the results.

4.4 Limitations of the Strategy

Despite its strengths, this approach has certain limitations:

- **Unobserved Confounders:** Propensity score methods cannot account for unmeasured variables, such as fatigue from driving or alcohol consumption, which may systematically differ between daytime and nighttime accidents.

- **Common Support Requirement:** PSM requires sufficient overlap in propensity scores between treated and control groups. Observations outside the common support region must be excluded, potentially reducing the effective sample size.

- **Model Dependency:** Both PSM and IPW rely on correctly specifying the propensity score model. Misspecification could bias the results.

5 Results

5.1 Logistic Regression Analysis

The logistic regression analysis, based on 93,050 records, finds important parameters influencing the likelihood of accidents during the day as opposed to at night. The findings provide a comprehensive understanding of the determinants of accident severity and highlight significant patterns. Important conclusions include:

- **Regional Differences:** Accidents are more likely to occur at night in metropolitan regions such as Roma, Milano, and Napoli. This could be attributed to higher nighttime activity levels, such as nightlife and commuting patterns. Conversely, daytime accidents are more frequent in Firenze, Genova, and Bologna. This trend likely reflect higher daytime traffic volumes due to tourism, commercial activities, and urban commuting. Cities like Padova show no statistically significant difference in the likelihood of traffic accidents occurring during the day versus at night

- **Climate and Road Conditions:** Wet pavements and adverse weather conditions (such as fog and heavy precipitation) are associated with nighttime accidents. These conditions impair drivers' ability to navigate safely and increase braking distances, particularly on poorly maintained roads.

- **Details of the Driver:** Accidents at night are more likely to involve younger drivers (18 to 29 years of age), while accidents during the day are more likely to involve older drivers (55+ years of age). This may reflect patterns in daily routines, as older individuals are less likely to drive at night and may prefer traveling during daylight hours. On the other hand, younger individuals tend to go out and enjoy nightlife more frequently.

These results demonstrate the causative interactions between the time of day and demographic, environmental, and geographical factors.

5.2 Key Findings: Propensity Score Methods

To assess the causal effect of nighttime driving on fatality rates, advanced propensity score techniques were employed. These included Propensity Score Matching (PSM) and Inverse Probability Weighting (IPW), ensuring the results addressed observable confounders effectively.

- **ATT (PSM):** -0.0125

  This indicates a 1.25 percentage point increase in the fatality rate for nighttime accidents compared to their matched daytime counterparts. Using PSM ensures that the comparison is made between units that are statistically similar across covariates, isolating the causal effect of nighttime conditions.

- **ATT (IPW):** -0.0100

  This shows a 1.0 percentage point increase in the fatality rate for nighttime accidents. IPW reweights the sample to emulate a randomized experiment, making the treated and control groups comparable in terms of observed covariates.

The consistency of these estimates across methods highlights the robustness of the findings. As Angrist and Pischke emphasize, robustness to different estimators strengthens causal claims, reducing concerns about method-specific biases.

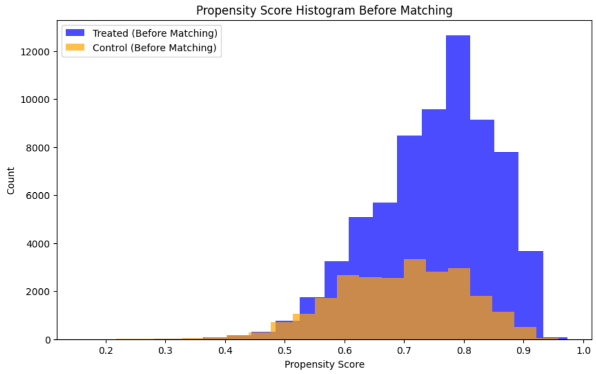
5.3 Visualizing Covariate Balancing and Outcomes

In the context of propensity score methods, visualizing covariate balancing and outcome differences is crucial for validating the effectiveness of the causal inference model. Figures 2 and 3 summarize the impact of PSM and IPW on covariate balance and outcome estimation.

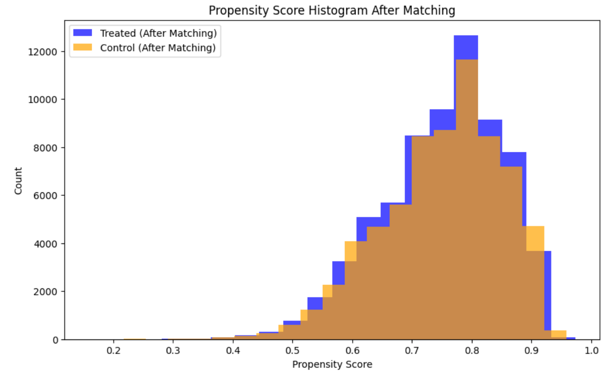
Before Matching: There is a clear imbalance between the treated (daytime) and control (nighttime) groups across propensity scores, indicating that the groups are not comparable. This imbalance underscores the need for matching to create comparability.

After Matching: PSM shows significantly improved overlap between the two groups, suggesting that the matching process has successfully reduced bias and improved comparability for causal inference.

IPW Results: The weighted propensity score distributions (Figure 3a) demonstrate significant overlap, confirming effective covariate balance. This indicates that the groups are now comparable in terms of baseline characteristics. The weighted outcome means (Figure 3b) show higher fatality rates for nighttime

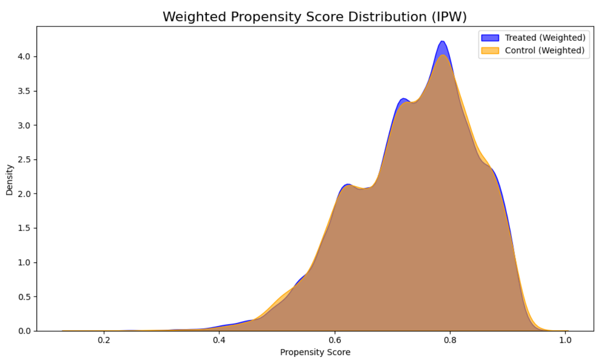


(a) Before Matching

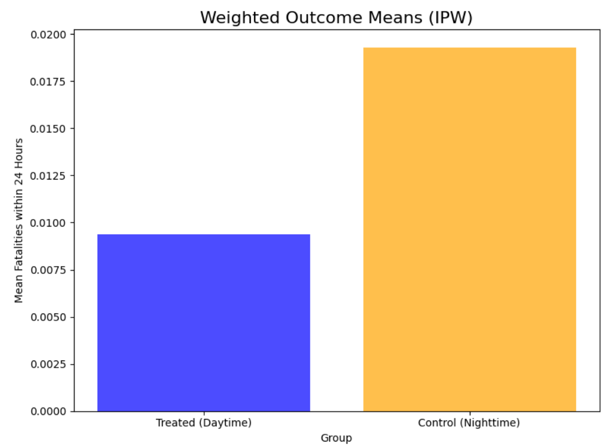


(b) After Matching

Figure 2: Propensity Score Distributions (PSM)



(a) Weighted Distribution (IPW)



(b) Weighted Outcomes (IPW)

Figure 3: IPW Results: Balancing and Outcome Estimation

accidents (~ 0.02) compared to daytime (~ 0.01). Figure 3a (Weighted Distribution) confirms this overlap, supporting the reliability of the estimates in Figure 3b. It exemplifies this by showing adjusted means after IPW, satisfying the conditional independence assumption necessary for a causal interpretation.

6 Discussion and Conclusions

Key Implications

The results provide actionable insights for policymakers to reduce nighttime accident fatalities:

- **Localized Interventions:** Provinces like Roma, Milano, and Napoli, which experience higher nighttime fatality rates, require targeted measures such as working with local businesses, especially those in nightlife and tourism, to promote safer transportation options (e.g., subsidized late-night taxis or ride-sharing)

- **Infrastructure Investments:** Road conditions significantly influence nighttime accidents. Enhancing lighting, road markings, and widening single-lane roads can mitigate risks. Prioritizing infrastructure improvements in high-risk areas will have a direct impact.
- **Driver-Specific Strategies:** Younger drivers (18–29 years) are disproportionately involved in nighttime accidents, suggesting the need for stricter enforcement of speeding and impaired driving regulations, particularly at night, including implementing random checks for speeding, alcohol consumption, and seatbelt use.

Conclusion

This study provides robust evidence that nighttime accidents are causally linked to higher fatality rates compared to daytime accidents. Using Propensity Score Matching (PSM) and Inverse Probability Weighting (IPW), the analysis estimates a 1 to 1.25 percentage point higher fatality rate for nighttime accidents, after addressing biases from observable confounders such as weather, road type, and driver demographics. These findings isolate the causal effect of time of day on accident outcomes, aligning with principles of causal inference outlined in *Mostly Harmless Econometrics*.[10]

This study emphasizes how important the time of day is in determining the results of traffic accidents. It emphasizes the necessity of focused, data-driven policy measures to enhance road safety by calculating the elevated risk of accidents during the night. Reducing deaths and saving lives requires addressing regional differences, improving infrastructure, and putting driver-specific solutions into practice.

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[11] World Health Organization, *Global Status Report on Road Safety*

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