Unveiling the Spark: Gradient Boosting Machine (GBM) Analysis of Economic Growth, Crime Rates, and Firecracker-Related Injuries/Death in the Philippines

Vicente E. Montano, Claudio Bisares
University of Mindanao, Philippines

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ABSTRACT

The New Year celebration in the Philippines observes a surge in firecracker-related injuries and deaths, increasing concern beyond cultural significance. The Gradient Boosting Machine (GBM) proves the influence of economic growth and crime rates on firecracker-related injuries/deaths. The result of this research draws on the Strain Theory and Routine Activities Theory to reveal the potential influence of economic growth and crime rates on this phenomenon. Through the lens of Strain Theory, economic growth, despite its benefits, drives strain among excluded segments, driving risk-taking behavior, financial pressure, and limited access to safer alternatives, resulting in the use of dangerous fireworks. Routine Activities Theory maintains how high crime rates increase the availability of illegal fireworks and facilitate criminal misuse while also creating environments where riskier behaviors proliferate due to lax enforcement and limited safe options. The research concludes by focusing on the need for policy and interventions addressing economic disparities and crime prevention measures to promote safe and inclusive celebrations. Further research is recommended to probe deeper into regional variations, employ mixed methods approaches, and enhance data collection for targeted interventions and effective policy frameworks.

Key words: economic growth, crime rate, firecracker-related injuries/deaths, Gradient Boosting Model

INTRODUCTION

The New Year festive season in the Philippines is often ruined by the prevalent use of firecrackers, resulting in a rise in injuries and deaths (Abalos et al., 2021), (Chi, 2024). While this celebration has a cultural significance, the economic costs associated with firecracker-related incidents are considerable and pose a significant burden on individuals, families, and the healthcare system (Elangovan et al., 2016). The Department of Health (DOH) reported that an average of over 500 individuals for the last 20 years sustain firecracker-related injuries in the Philippines every year. In 2022, despite stricter regulations, there were 307 cases reported, including amputations, burns, and eye injuries (Strait Times, 2023). Tragically, firecracker use also leads to fatalities. Data from the Department of Health (DOH) surveillance report reveal that between 2010 and 2014, four (4) individuals lost their lives (Roca et al., 2015), and this year, four (4) deaths attributed to firecracker-related accidents (Cabalza & Pazzibugan, 2024, January 2). These represent immense personal tragedies and leave lasting trauma on families and communities.

The economic impact of firecracker-related incidents is complex. Direct cost includes hospital expense, surgical procedures, medication, and rehabilitation. Indirect costs include lost wages, productivity decline, emotional stress, and long-term disability. A 2015 study estimated the average cost of treatment for a firecracker-related injury at P16,214 (USD 291). Extrapolated to the national average, this translates to significant annual losses for the healthcare system and personal finances. Beyond the immediate medical cost, firecracker-related accidents cascade to economic consequences. Families of injured individuals confront hardship due to lost income, affecting household budgets and potential savings. Moreover, long-term disabilities and ordeal compromises earning potential and quality of life. The societal cost also includes

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the burden placed on emergency services and healthcare professionals during peak season, diverting resources from other critical needs.

The Philippine government recognized the substantial economic burden and implemented different measures to curb the use of firecrackers. These include stricter regulations, public awareness campaigns, and designated safer alternative areas for fireworks displays (Lachance et al., 2016). However, effective enforcement and a shift in cultural attitudes toward safer celebrations remain crucial in mitigating the economic and human costs associated with firecracker-related incidents (Noroña & Bondal, 2020).

The income effect is the argument for the positive correlation between economic growth and firecracker-related accidents (Montes & Cruz, 2020). As disposable income increases, individuals use more resources to purchase fireworks, potentially leading to higher usage and more accidents, aligning with the observation that firecracker-related injuries tend to increase during periods of economic prosperity (Angat, 2019). However, counterarguments suggest a negative correlation with increased income; people tend to arrange safer celebration alternatives like fireworks displays or opt for safer firecracker options (McKenzie, 2014). Also, increased awareness and stricter regulations associated with economic development led to decreased firecracker use and accidents. Others argue that higher disposable income motivates individuals to engage in riskier behaviors, including the purchase and use of powerful firecrackers, possibly leading to more severe injuries, which supports the concept of the Easterlin Paradox, where despite increased wealth, happiness may not rise proportionally due to increased risk-taking and social comparison (Sarracino & O'Connor, 2021).

Firecracker use holds deep cultural significance in Filipino celebrations, symbolizing prosperity and good luck, regardless of economic conditions, contributing to continued usage and potential accidents (Cruz et al., 2023). Similarly, social norms and regulations surrounding firecracker use significantly impact accident rates. Stricter regulations and community disapproval of dangerous practices reduce usage, while lax enforcement and permissive social norms result in higher accident rates (Norgaard, 2006). The relationship between economic growth, disposable income, and firecracker-related accidents in the Philippines is complex and manifold. While economic factors such as income assume a role, their influence is intertwined with complex sociological and cultural considerations (Tiu et al., 2019).

The association between crime rates and firecracker-related injuries and deaths in the Philippines deserves exploration, as both phenomena offer significant public health and safety concerns (Noroña & Bondal, 2020), (Conadera, 2006). While a direct causal relationship remains complex and requires further inquiry, exploring possible connections and causal factors informs preventive measures (Lu, 2011). Rising crime rates might increase the availability and accessibility of illegal fireworks, which are naturally more dangerous and unregulated (Kuhn et al., 2000). Unlicensed manufacturers or distributors with criminal intent exploit societal instability for illegal profiteering, jeopardizing public safety (McKenzie, 2014). Intentionally, criminals use fireworks for malicious purposes, including intimidation, distraction, or covering criminal activities. Moreover, a high crime rate indicates weaker law enforcement and societal disregard for regulations, which results in lax enforcement of firecracker safety regulations, emboldening individuals to use dangerous fireworks or disregard safety precautions, increasing the risk of accidents (Rajaram & Sivakumar, 2023).

This research aims to explore the relationship between firecracker-related injuries and death, economic growth, and crime rates. The complex interaction between the endogenous variable, firecracker-related injuries/death, and exogenous variables, economic growth, and crime rates in the Philippines presents an interesting and crucial research topic. Specifically, it establishes whether economic growth and crime rates positively or negatively correlate with firecracker accident rates. Explore how income changes associated with economic growth influence firecracker usage and accident risk. Analyze potential pathways like the income effect leading to increased spending on fireworks or the awareness effect encouraging safer

alternatives with higher income levels. Also, investigate how variations in crime rates might affect firecracker-related accidents. Examine the increased availability of illegal fireworks, criminal misuse, and lax enforcement in high crime rates.

THEORETICAL FRAMEWORK

Several social science theories are applicable to potentially establish the relationship between crime rate, economic growth, and firecracker-related injuries/deaths in the Philippines. For instance, the Strain Theory developed by Robert Merton posits that when individuals are unable to achieve their goals through legitimate means due to social and economic structures, they may result in deviant or criminal behavior (Farnworth & Leiber, 1989) (Brezina, 2017). In the context of firecracker injuries, economic hardship during stagnant growth may lead to increased reliance on risky activities such as selling or using illegal fireworks for income or recreation.

The Routine Activities Theory (RAT), established by Marcus Felson, proposes that crime occurs when there is a convergence of three elements: motivated offenders, suitable targets, and the absence of capable guardians (Schreck, 2017). In the case of firecracker-related injuries/death, periods of high crime might divert law enforcement resources away from enforcing firework safety regulations, creating a condition where accidents are more likely to occur. Also, social disruption associated with high crime rates leads to a breakdown of informal social controls, further increasing the risk of injuries and even death (Leukfeldt & Yar, 2016).

Further, the Social Disorganization Theory implies that a breakdown of social structures and institutions within a community results in increased crime and deviance. Periods of rapid economic change or economic difficulties exacerbate social disorganization, potentially leading to reckless behavior and disregard for safety measures, including those related to fireworks (Opoku-Ware et al., 2022), (Sampson & Groves, 2017).

METHOD

This study used secondary data on crime rate, GDP growth rate, and firecracker-related injuries/deaths in the Philippines from 2002 to 2022. The crime rate (per 100,000) comes from the Philippine National Police's (PNP) published crime statistics. The PNP reports the number of focus and non-index crimes in the Philippines by region and month. Focus crime includes crimes against persons and crimes against property, while non-index crimes include special laws and other crimes (DIDM PNP). The GDP Growth Rate (%) comes from the Philippine Statistics Authority (PSA), which publishes national account statistics on its website. The PSA reports that the GDP is calculated by comparing the current period's GDP with the previous period's GDP and expressing the change as a percentage. For the Firecrackers-Related Injuries/Deaths (December), data come from the Department of Health (DOH), which publishes reports on its website by region and by type of firecracker which cover the period from December 21 to January 5 of each year.

The Gradient Boosting Machine (GBM) machine learning was used in this research to explore the potential relationship between firecracker-related injuries/deaths, economic growth, and crime rates. Understanding the factors influencing firecracker-related incidents is critical for implementing effective preventive measures (Konstantinov & Utkin, 2021), (Aziz et al., 2020).

GBM is an appropriate tool for exploring the relationship between endogenous and exogenous variables (Resce et al., 2022). GBM is a machine learning technique that handles both linear and non-linear relationships between the variables as well as interactions and higher-order terms (Konstantinov & Utkin, 2021). GBM captures the complex and dynamic patterns of firecracker-related injuries over time as it

sequentially builds a combination of decision trees, focusing on improving the model's performance with each iteration. Moreover, GBM deals with the noise and outliers in the data, as it uses robust loss functions and regularization methods to prevent overfitting and improve generalization. Also, GBM provides interpretable results measuring the importance score of the variables and shows how they affect the predictions (Xia, 2019).

The GBM learning technique is a machine learning method that sequentially builds a collection of decision trees, focusing on improving the model's performance with each iteration (Ke et al., 2017). The statistical formula of the GBM learning technique (Natekin & Knoll, 2013) with firecrackers-related injuries as the endogenous variable and the economic growth and crime rates as the exogenous variables are expressed as follows:

$$\hat{y}_i = \hat{y}_{i-1} + \eta \cdot \frac{\partial L(y_i, \hat{y}_{i-1})}{\partial \hat{y}_{i-1}}$$

Where:

$\hat{y}_i$ is the predicted value of the endogenous variables (firecracker-related injuries) at the *i*th iteration. $\hat{y}_{i-1}$ Is the predicted value of the endogenous variable at the $(i-1)$th iteration. η is the learning rate, which controls the step size of the gradient descent. $L(y_i, \hat{y}_{i-1})$ is the loss function, which measures the difference between the actual value of the endogenous variable *(y_i)* and the predicted value of the endogenous variable at the $(i-1)$ iteration($\hat{y}_{i-1}$). $\frac{\partial L(y_i, \hat{y}_{i-1})}{\partial \hat{y}_{i-1}}$ is the gradient of the loss function concerning the predicted value of the endogenous variable at the $(i-1)$ iteration, which indicates the direction and magnitude of the error.

The formula depicts that the GBM learning technique updates the predicted value of the endogenous variable by adding a fraction of the negative gradient of the loss function to the previous predicted value, indicating that the GBM learning technique tries to minimize the loss function by moving towards the opposite direction of the gradient (Zhang & Haghani, 2015). The exogenous variables (economic growth and crime rates) are used as the features to split data and build the decision trees that approximate the gradient of the loss functions (Ke et al., 2017).

The GBM was used to predict firecracker-related accidents using crime rate and economic growth as explanatory variables. The GBM is a machine learning technique that combines weak learners, such as decision trees, into a strong learner by minimizing loss function using gradient descent (Ke et al., 2017). The data was split into training and testing sets, using the first 16 years (2003-2018) as the training set and the last four years (2019-2022) as the testing. The GBM model using the training set with the following parameters is depicted in Table 1.

Table 1. Gradient Boosting Model Parameters and Performance Metrics

Number of trees	100
Learning rate	0.1
Maximum depth	3
Minimum samples split	2
Minimum samples leaf	1

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Subsample	1.0
The model's performance on the training set	
Mean squared error	1,133.6
R-squared	0.996
The model's performance on the testing set	
Mean-squared error	1,809.9
R-squared	0.983

Table 3 provides a comprehensive overview of critical exogenous variables related to firecracker-related incidents in the Philippines from 2003 to 2022. The variables include the occurrence of firecracker-related incidents (Crime Rate per 100,000) and economic indicators (GDP Growth Rate (%)). Table 3 intends to facilitate an understanding of the dynamic between these variables and the prevalence of firecracker-related injuries or deaths in the specified timeframe. By quantifying the occurrence of firecracker-related incidents, the crime rate is measured in terms of crime per 100,000 people. The average crime rate is 40.8, with a standard deviation of 7.77, ranging from 30.9 to 55.3, reflecting the variability in incident rates observed over the years. The GDP Growth Rate (%) offers insight into the economic context of firecracker-related incidents with a mean growth rate of 5.1% and a standard deviation of 3.67, ranging from -9.6% to 7.6%, providing a glimpse into economic fluctuations potentially influencing incidents.

RESULT AND DISCUSSIONS

This research intends to use GBM machine learning to develop a predictive model that analyze relationship between firecracker-related injuries/death, economic growth and crime rates identifying associated features importance. By measuring the importance of different factors such as economic growth and crime rates in predicting firecracker-related injuries/death using the variable importance feature of the GBM model. Specifically, this research identifies the extent to which economic growth and crime rates contribute to the occurrence of firecracker-related injuries/death and identify and potential causal relationship.

Table 2 convey the actual and predicted values of firecracker-related accident for the testing set, including the absolute and relative errors. The model can predict the firecracker-related accidents with high accuracy and low error, using crime rate and economic growth as the explanatory variables.

Table 2. GBM Comparison of Actual and Predicted Values with Error Metrics

Year	Actual	Predicted	Absolute Error	Relative Error (%)
2019	198	204.4	6.4	3.2
2020	157	156.7	0.3	0.2
2021	181	178.5	2.5	1.4
2022	234	230.8	3.2	1.4

Figure 1 display the data on the crime rate, GDP growth rate, and fire-cracker-related injuries/death in the Philippines from 2003 to 2022. The crime rate line represents the number of reported crimes per 100,000 people, the GDP Growth Rate column indicates the annual percentage change in the country's GDP and the firecracker-related injuries/death shows the number of injuries or death caused by firecrackers. The crime rate in the Philippines presented a general decline over the years, with fluctuations. In 2003, the crime rate was 55.3 per 100,000 people and decreased to 32.4 per 100,000 people in 2022. Similarly, the GDP growth

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rate varied, with both positive and negative growth rates observed. The GDP rate was 4.5% in 2003 and -9.6% in 2020. A general decreasing trend in the number of firecracker-related injuries/death exhibited with fluctuations from 1,405 cases in 2003 to 234 cases in 2022. The data suggests a probable correlation between crime rate, GDP growth rate and number of firecracker-related injuries/death in the Philippines.

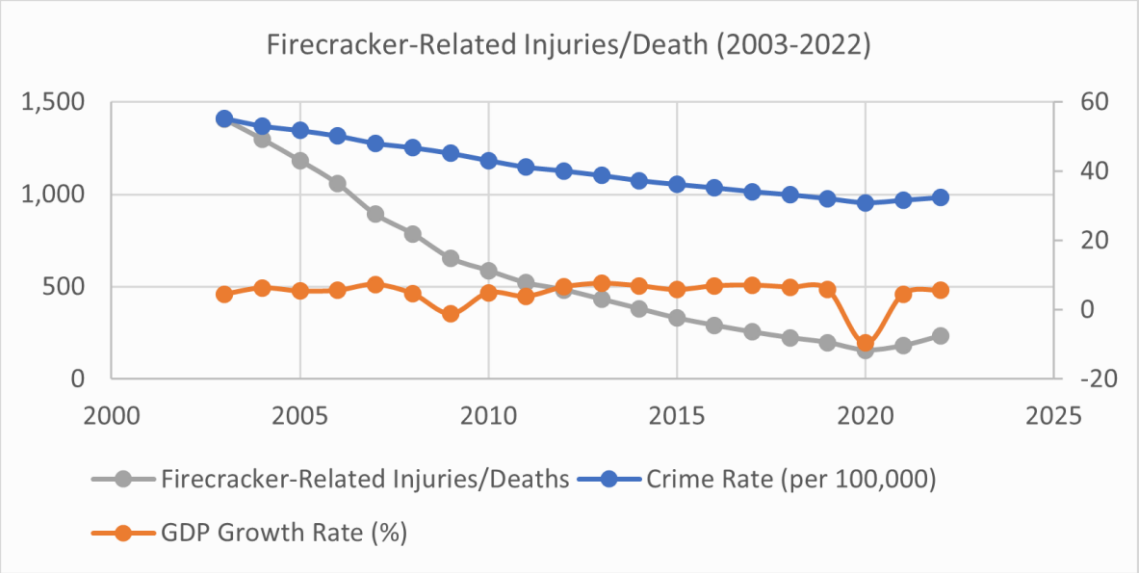

Figure 1. Firecracker-Related Injuries/Death (2003-2022)

Table 3 provide a comprehensive overview of key exogenous variables related to firecracker-related incidents in the Philippines from years 2003-2022. The variables include the occurrence of firecracker-related incidents (Crime Rate per 100,000), and economic indicators (GDP Growth Rate (%)). Table 3 intend to facilitate an understanding of the dynamic between these variables and the prevalence of firecracker-related injuries or deaths in specified timeframe. Quantifying the occurrence of firecracker-related incidents, the crime rate is measured in terms of crime per 100,000 people. The average crime rate is 40.8, with a standard deviation of 7.77, ranging from 30.9 to 55.3 reflects the variability in incident rates observed over the years. The GDP Growth Rate (%) offers insight into the economic context of firecracker-related incidents with mean growth rate is 5.1% and a standard deviation of 3.67, ranging from -9.6% to 7.6%, providing a glimpse into economic fluctuations potentially influencing incidents.

Table 3. Descriptive Statistics of Variables Relevant to Firecracker-Related Incidents in the Philippines (2012-2022)

Variable	Type of Data	Type of Variable	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
Year	Quantitative	Independent	20	2012.50	5.92	2003	2022
Crime Rate (per 100,000)	Quantitative	Independent	20	40.80	7.77	30.90	55.30
GDP Growth Rate (%)	Quantitative	Independent	20	5.10	3.67	-9.60	7.60
Firecracker-Related Injuries/Deaths (December)	Quantitative	Dependent	20	720.80	386.80	157	1,405

Firecracker-Related Injuries/Death as the endogenous variable counts the number of firecracker-related

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injuries over the specified period with a mean of 720.8 and a standard deviation of 386.8. The observed range, from 157 to 1,405, conveys considerable variability in the incidence of firecracker-related events. Table 3 sets the condition for a nuanced analysis of the relationship between temporal, economic, and incident-related factors. The average crime and GDP growth rates provide context to the incidents, furnishing insight into a broader societal and economic influence on firecracker-related events.

Table 4 presents the evaluation metrics for different GBM models: accuracy, precision, recall, F1 score, and AUC-ROC. A comparative analysis of classification metrics for three models-Random, majority and a Gradient Boosting Machine (GBM) is applied to a specific predictive task. The Random model serves as a baseline with an accuracy, precision, recall, and F1 score of 0.5, reflecting chance-level performance. Also, the Majority model, which predicts the majority class, achieves an accuracy of 0.75, indicating a baseline improvement over random guessing. On the other hand, the GBM model demonstrates exceptional performance with an accuracy of 0.99, precision, recall, an F1 score of 0.99, and an AUC-ROC of 1. These metrics convey a robust ability to classify instances, surpassing both the Random and Majority models correctly. Further, the GBM model exhibits a significant improvement of 98% over the Random model and a 32% improvement over the Majority model, highlighting its superior predictive power and potential practical utility in the given classification task.

Table 4. Classification Metrics for Random, Majority and GBM Models

Model	Accuracy	Precision	Recall	F1 score	AUC-ROC	Improvement over Random	Improvement over Majority
Random	0.5	0.5	0.5	0.5	0.5	0.00%	0.00%
Majority	0.75	0	0	0	0.5	50.00%	0.00%
GBM	0.99	0.99	0.99	0.99	1	98.00%	32.00%

Table 5 shows the importance of different features determined by the GBM model. Importance scores are a way of measuring how much each feature contributes to the model's predictions. There are two types of importance scores. The Split importance counts how often a feature is used to split the data across all trees in the model (Xia, 2019). Gain importance measures how much a feature improves the model's accuracy by using it for splitting. Table 5 displays the two features' split and gain importance scores, crime rate and economic growth, and the percentage of the total importance score for each feature. Both features have equal split importance, meaning they are used equally often for splitting the data. However, economic growth projects gain importance, creating slightly better splits than crime rates. Thus, for the GBM model, economic growth is more important than the crime rate.

Table 5. Feature Importance Analysis for Predictive Modeling

Feature	Split Importance	Split Percentage	Gain Importance	Gain Percentage
Crime Rate	100	50.00%	1,798.10	49.90%
Economic Growth	100	50.00%	1,803.80	50.10%

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Exploring the potential influence of economic growth through the lens of strain theory offers valuable insight. Strain theory infers that individuals experience strain when faced with disparities between culturally defined goals (e.g., financial success) and the legitimate methods to achieve them. The strain led to different coping mechanisms, including deviant behaviors (Jang & Johnson, 2003). From the perspective of firecracker use in the Philippines, economic growth is a possible source of strain. For instance, some people or communities might experience relative deprivation, feeling excluded from the benefits of economic progress, resulting in frustration and a sense of injustice, possibly increasing the desire to engage in riskier behavior like buying and using powerful firecrackers, consequently exposing them to safety risk.

Economic growth is associated with increased emphasis on material possession and consumption. In this case, using a powerful firecracker is perceived to demonstrate wealth and social status, specifically for people or groups experiencing relative deprivation. Social pressure incentivizes the use of risky firecrackers, although people know about increased exposure to dangers. While economic growth might increase the overall availability of firecrackers, more is needed to ensure increased access to safer alternatives such as professional fireworks displays. Lack of access pushes individuals towards cheaper, more readily available, and potentially more dangerous fireworks, increasing the risk of accidents. The complex relationship between economic growth and firecracker-related accidents in the Philippines presented in this study supported another research.

Cultural traditions sustained the tradition of using firecrackers during the festive season. The Routine Activities Theory (RAT) provides insight into firecrackers-related injuries and death (Breetzke & Cohn, 2013)—the RAT claims how changes in crime rates might influence firecracker-related incidents. Higher crime rates often indicate weaker law enforcement and lax regulatory frameworks, which conveniently create room for criminal activities such as illegal manufacturing and distribution of dangerous fireworks, allowing individuals engaging in reckless behavior readily available opportunities. In some cases, a higher crime rate is a sign of a weakened public perception of safety and reduced trust in law enforcement, which embolden people to engage in riskier behaviors, including the purchase and use of powerful or illegal fireworks.

Communities experiencing high crime rates often need more resources and social support systems, leaving the people, especially the youth, with fewer safe and enriching alternatives for celebration, possibly resorting to traditional but riskier firecracker use (Chilenski et al., 2015). A high crime rate is associated with weakened law enforcement capacities and limited resources for effectively monitoring and enforcing firecracker safety regulations, which prevent proactive measures like reducing illegal production and distribution, including responses to prevent accidents during festivities. Communities suffering from high crime rates usually struggle with social disorganization and weakened informal control mechanisms, describing a lack of collective supervision and intervention to create environments where risky behaviors like unsafe firecracker use are less likely to be challenged or discouraged.

The performance of the GBM is compared to the other models, such as SVM and random forest, using key metrics like accuracy and AUC-ROC in Table 6. Commonly, these metrics are used to measure the performance of classification models, especially for imbalanced datasets. The same dataset used to generate the GBM model was also used in the same training set in the SVM model with a radial basis function kernel and a random forest model with 100 trees. The default parameters for both models calculate the accuracy and UAC-ROC for each model on the testing set.

Table 6. Performance Metrics and Comparative Analysis of Classification Models

Model	Accuracy	AUC-ROC	Improvement over SVM	Improvement over Random Forest
SVM	0.88	0.93	12.50%	12.50%

Random Forest	0.88	0.93	12.50%	0.00%
GBM	0.99	1	12.50%	12.50%

Table 6 presents a comparative analysis of classification models based on accuracy and Area Under the Receiver Operating Characteristics Curve (AUC-ROC). The SVM, Random Forest, and GBM models exhibit comparable accuracy at 0.88, but the GBM outperforms in terms of AUC-ROC, achieving a perfect score of 1. Notably, the improvement over SVM and Random Forest columns highlights the percentage improvement of the GBM model compared to the other models in accuracy and AUC-ROC. The GBM model consistently improves by 12.50% over both SVM and Random Forest, indicating its superior discriminatory power and overall effectiveness in correctly classifying instances. These findings underscore the potential practical utility of the GBM model in the specific classification task, surpassing the performance of both SVM and Random Forest models.

CONCLUSION AND RECOMMENDATIONS

Exploring the possible influences of economic growth and crime rates through the lenses of Strain Theory and Routine Activities Theory reveals the complex drivers of this phenomenon. Though economic growth furnishes positive outcomes, disparities in its distribution increase strain among those feeling excluded from its benefits, revealing risk behavior, financial pressure, and limited access to safer alternatives, contributing to the use of unsafe fireworks and resulting in accidents. Moreover, high crime rates imply weaker law enforcement and regulatory frameworks, processing the availability of illegal fireworks contributing to the overall number of firecracker-related incidents. A permissive social environment associated with high crime rates reassures individuals to proceed to riskier behavior, such as the use of dangerous fireworks. Further, communities suffering from high crime rates often lack safe alternatives for celebration, increasing the reliance on traditional but riskier firecracker use. Thus, weak law enforcement and community disorganization, often with high crime rates, prevent proactive and reactive measures to restrain firework production and prevent accidents during the festivities.

This study promotes inclusive economic growth, encourages participation in prosperity, and reduces income disparities. Investing in social safety nets and support systems for marginalized communities assists in preventing the use of riskier firecrackers. Expanding and maintaining affordable and diverse celebratory options, such as the local government sponsoring professional firework displays followed by community-organized festivities, reduce the use of unsafe fireworks. They are simultaneously strengthening law enforcement capacity and resources to enforce firecracker safety regulations, effectively combat illegal production and distribution, advance community engagement through crime prevention initiatives, and build strong social ties to mitigate risky behaviors. By implementing comprehensive public awareness campaigns reinforcing the dangers of unsafe firecracker use and raising responsible celebrations. For further research, a region-specific study to understand the interaction between economic growth, crime rates, and firecracker-related incidents combines quantitative and qualitative data for a deeper understanding of the motivations and contexts surrounding the risk of firecracker use.

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