A Quantitative Study on Real-Time Police Patrol Route Optimization using Dynamic Hotspot Allocation

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***Abstract*—A quantitative study on the optimization of police patrol routes in real-time using dynamic hotspot allocation is presented in this article. Ensuring public safety necessitates addressing the difficulties law enforcement agencies encounter in optimizing patrol routes within limited resources. In dynamic environments, static patrol route planning and traditional random routing are inadequate. In order to prevent crime, this study suggests using big data analysis to pinpoint crime hotspots and create patrol routes that are most effective. Our suggested approach, when paired with the Random Forest algorithm, predicts crime-prone areas by combining 911 incident response data and crime datasets. This allows for the efficient use of police resources and successful preventive measures. A greedy algorithm is used to steer patrol units toward the best routes, maximizing their presence close to hotspots. Besides, a Hamilton way is powerfully made based on overhauled hotspots and crisis call hubs. Whereas the spatial selection technique addresses restrictions of randomized investigation, productive policing remains pivotal for societal well-being and financial development. Progressions in innovation enable decision-makers with real-time data on criminal exercises, guaranteeing resource-friendly strategies inside budgetary imperatives. Successful communication with the public is crucial, as security impacts different perspectives of society, including venture choices. Hence, cutting-edge approaches are crucial for informed decision-making and keeping up with general security.**

Keywords*—*Route optimization; redesigning police patrol; data-driven strategies; novel patrol routing; random forest; real-time crime prediction; crime data; 911 incident response; hamilton path

I. Introduction

The primary significance of this study lies in its imaginative approach to real-time police patrol route optimization utilizing dynamic hotspot allocation [1]. Existing literature frequently lacks comprehensive techniques to address the impediments of conventional patrol strategies, especially in dynamically changing situations where criminals adjust their behavior. This think about bridges this gap by proposing a strategy that integrates big data analysis, prescient policing algorithms, and real-time information to optimize patrol routes viably.

Police service has to build resilience to known and unknown human events, including crime. Criminals also constantly change depending on their environment and how the police service responds to emergency services or crime cases [1]. Developing and embracing technology to identify crimes easily and react as quickly as possible is a great resource. Preempting future crimes and their attendant consequences ensures that the potential impact is lessened, thus promoting public safety and security. Police officers have to be at the right place at the right time and use the right tools, devices, and equipment to arrest criminals [1]. Information is power, but how the information is received is much more important to deter crime. Route optimization for patrols can be achieved with increased funding for police technology [1]. The police force must also be enabled to learn how to utilize technology to deter crime in the main crime hotspots. Technology assists in positioning the officers through configuration; hence, they will be able to respond to incidents early and efficiently. Predictive policing could be another subtle term for route optimization, as it is easier to control and direct police patrols [1].

Dispatchers currently identify the crime hotspots and direct the police to respond or direct the response units. Whenever the crime response units are not attending to an incident, they patrol the same crime scenes to deter crime [1]. In hotspots, the earlier the police can respond to an incident, the more likely an area will have tranquility compared to areas where the police do not respond promptly to crime alerts. Apart from deterring crime, the police on patrols must be positioned in configurations that enable them to promptly reach the areas in demand [1].

The current practice still needs to demonstrate that there are a lot of challenges or issues associated with the response unit in their patrol areas. Route optimization, therefore, will assist in implementing methods of mapping crime scenes and configuring the hotspots to assist the police personnel on patrols. Real-time positioning will help avoid any variability while bolstering proactive positioning and allocating enough police personnel for patrol tasks. The practice now is that the rapid response to a crime scene or crime hotspot is at least three hours, but with route optimization, the response time will be reduced to less than three hours [1]. This research proposes real-time positioning to optimize police positioning in crime hotspots using real-time information.

The value added by this paper lies in its inventive approach to real-time police patrol course optimization utilizing dynamic hotspot allocation. Not at all like other papers, this work emphasizes the need to preempt future violations and their results to advance public security and security viably [1]. By leveraging innovation to distinguish crimes effectively and respond rapidly, this investigation proposes a strategy that diminishes reaction time to crime episodes, improving, by and large, watch productivity. The presentation highlights the special commitment of this thinking in tending to the challenges related to conventional watch strategies and emphasizes the significance of proactive situating and allotment of police staff in crime hotspots.

II. Background

The study addressed several challenges faced by the Atlanta Police Department's design of patrol zones, which are discussed in the piece. A quickening population growth rate, shifting demographics and traffic patterns, and an uneven distribution of the policing burden among regions are some of these difficulties. Due to these elements, some areas saw increased crime rates, and emergency call response times were lengthened, especially in urgent situations like violent crimes [2]. The article also emphasizes that APD has problems finding and keeping officers to handle the increased workload. By redistributing police workload and speeding up response to emergency calls, the suggested data-driven optimization framework seeks to resolve these difficulties.

This article explores the challenges law enforcement organizations experience when planning patrol routes that will best enable them to respond to urgent reports of crimes. The paper demonstrates the shortcomings of conventional patrol route planning techniques and suggests data-driven strategies for improving patrol routes [2]. Urban environments are dynamic, necessitating real-time data to successfully optimize patrol routes, which is one of the difficulties mentioned in the study [3]. The article suggests using machine learning algorithms to examine prior criminal activity, movement patterns, and emergency contact data to forecast upcoming illegal activity and patrol routes.

By redesigning police patrol areas in cities using optimization techniques, it is possible to handle another issue raised in this article: the need to balance police workload across regions and speed up response to emergency calls. The article emphasizes that law enforcement organizations must implement data-driven strategies to optimize patrol routes and improve public safety [4].

III. Problem Statement

The problem of efficient patrol path generation for police officers to ensure public safety is given limited police resources [3]. Traditional random routing is limited by providing police presence during crime events. The problem with static patrol route planning is that it needs to consider the constantly changing environment and dynamic human activities in urban areas that can influence crime patterns [4]. There is a need for optimal police patrol routes in a dynamic environment that considers real-time sensor data and human mobility data. The problem is coordinating police officers to visit time-dependent crime hotspots to prevent crime occurrences and attend real-time emergencies [3].

There is a need to leverage human movements, specifically location-based social network check-in data, to better predict crime hotspots in the next time interval. The problem is generating an initial patrol strategy using prediction results and continuously refining the route based on real-time demand from emergency call data. The goal is to minimize an area's crime risk in a time interval and the time of traveling. New evaluation methodologies and metrics are needed to evaluate the effectiveness of dynamic police patrolling route planning using real-world data. The study aims to utilize the potential of big data analysis to identify crime hotspots in actual police policy and generate optimized patrol routes for crime prevention [1].

IV. Research Questions

Some of the research questions that this paper aims to address are as follows:

- How can proactive patrolling be one of the notable methods used by the security sector to facilitate action that can help counter the cases to ensure that critical offenses and offenders suspected of crimes such as human trafficking, drug trafficking, terrorism, and other major violations if not contained can lead to severe threats to national security?
- Can crimes easily be tracked using records from the relevant databases?

V. Existing Case Studies

A. Novel Patrol Routing Framework using Hotspots and Traffic Data

In study [5], the authors proposed a novel patrol routing approach using hotspot areas and traffic data. The authors implement the routing in two phases: Identifying the hotspot locations based on crime and various community data and optimizing hotspot location patrol. The study implements data collection, preprocessing, and correlation analysis in the first phase to discover hotspots. The study collects data from four data categories: Crime, Building, Population, and Environment. The preprocessing step involves grouping data based on geolocation into grids and categorical to numerical data conversion. After preprocessing, the authors utilize the Pearson correlation coefficient measure between community and crime data to measure the correlation strength in each grid area. The study also factors data set size in each grid as density measurement to classify specific grid locations as hotspots.

In phase 2, the authors use a genetic algorithm to determine the optimal routing pattern between the hotspots. The study's fitness function is to reduce the response time and length of the patrol route. The authors run the genetic algorithm until it converges to find the most significant fitness function, thereby obtaining the optimized patrol route [5]. The authors evaluate their proposed novel approach using real-time traffic data. Furthermore, they consider the fitness function by comparing the random traffic data to the optimal traffic data. The results show a response time save of 3000 minutes for response time at all test locations. The study has multiple shortcomings, including choosing Pearson coefficient correlation, lack of quantitative measures to evaluate the algorithm performance, and insufficient preliminary analysis and decision choice explanation in choosing the genetic algorithm.

B. Data-Driven Police Route Optimization Framework

In the second case study, we explore a survey that uses a Data-driven routing and Optimization framework to redesign police patrol routes [4]. The authors developed a stochastic model for routing and implemented their framework in the city of Atlanta. As per the study, the current method for police zone design in Atlanta is based on historical boundaries and does not embed crucial factors such as crime incidence or population demographics. The current approach causes suboptimal allocation of police resources and increased crime rates. The study proposes a data-driven optimization approach that includes crime incidence-impacting factors, such as population density, median household income, education level, and school enrollment. The dataset consists of emergency call data (911 data) and data from the American Community Survey.

The study first builds a transition matrix with saturated and unsaturated states based on travel time, call arrivals, and service rates. A police dispatch unit can have either an upward transition state that denotes a transition from an unsaturated to a saturated or a downward shift that represents a transition from a saturated to an unsaturated state. The authors use a spatiotemporal model with maximum likelihood estimation as the cost function. Finally, the authors evaluate their model using real-world data from Atlanta and compare its performance to the existing design. They found that their approach reduced crime rates by up to 9% in some areas and increased police efficiency by reducing incident response times. Although the study's model incorporates comprehensive features and evaluates its performance on real-world data, it relies on numerous assumptions that do not always comply with real-world situations. The premises include an equal number of police beats for each city zone, the closest police dispatch on emergency calls, and the First-In-First-Out (FIFO) rule on backlogged calls.

C. Real-Time Predictive Patrolling Framework

In the third case study, we review a paper that proposes a new approach to optimizing law enforcement patrolling and routing using real-time spatiotemporal data from various sources [2]. The study aims to improve the effectiveness and efficiency of law enforcement efforts, particularly in identifying and deterring criminal activity. The authors developed a Real-Time Predictive Patrolling and routing (RTPR) system that incorporates data from multiple sources, including emergency calls, police vehicle GPS locations, and historical crime data. The authors propose a two-phase framework: criminal activity prediction and patrol route optimization.

The RTPR system uses a dynamic greedy approach to find the optimal patrol routes using various factors such as the dispatch vehicle availability, response time, and the likelihood of criminal activity. The model uses a Random Forest classifier to predict regional hotspot zones. After hotspot prediction, a greedy algorithm optimized the patrol routes within hotspots and emergency calls. The cost function approach is to collect the maximum reward with minimal travel time. To evaluate the RTPR system performance, the authors apply the model to real-world data from Seattle and Melbourne. The quantitative evaluation metrics for comparison include robustness, efficiency, and idle.

The results show that the proposed framework achieves high efficiency and idle times compared to traditional greedy algorithms. Although the study proves that the data-driven optimization approach can reduce crime rates and improve police efficiency, it must comprehensively evaluate the system. For example, the study does not address potential unintended consequences, such as increased police surveillance in specific neighborhoods or changes in community dynamics due to changes in police resource allocation.

VI. Proposed Approach

A. Crime Event Prediction

We have compiled a range of features to serve as predictors in our crime event prediction model, encompassing historical, geographic, and mobility factors. To ascertain the density of crime incidents at nodes following temporal intervals, we draw upon historical crime data, including venue type, spread, and regional variety. Subsequently, a random forest (RF) algorithm [6] was employed to identify and forecast potential hotspot nodes during the subsequent time interval, owing to its non-parametric nature and applicability in a wide range of heterogeneous and multidimensional feature environments.

B. Patrol Route Planning Algorithm

A version of a greedy algorithm from the crime prediction may be used to optimize police patrol routes to achieve the greatest reward with the fewest number of trips. This method considers various data, including patrol start and end times, cumulative transit time across nodes, and the average time police officers spend at each node. Furthermore, a function is used to evaluate the significance of individual patrol nodes and factor this into the result [7], ensuring that nodes of crucial importance are considered and accounted for and allowing the algorithm to recognize suitable routes for beat cops through frequent updates regarding 911 emergency response occurrences and potential criminal hotspots.

VII. Dataset Preliminary Analysis

A. Crime Data

Using data.seattle.gov/Public-Safety as our source, we have retrieved and are now reviewing the columns of the crime dataset. This dataset provides an in-depth look at crime in Seattle, detailing the Report Number, Offense ID, Offense Start and End times, Report, Offence, and Precinct information, as represented in Table I.

The data collected from police reports, renowned for their accuracy, has resulted in high reliability. An analytical data review has been conducted to ensure it is comprehensive and correct. This data contains much information concerning the incidence of more than one million criminal acts in Seattle between 2007 and 2013.

In Fig. 1, from 2007 to 2013, there were more crimes related to property than crimes concerning persons.

Fig 2 shows the distribution of the crimes per month across the year.

In Fig. 3, we can see the distribution of the number of crimes based on .their types.

TABLE I. CRIME DATASET

Column Name	Column Description
Report Number	Primary key/UID for the overall report. One report can contain multiple offenses, as denoted by the Offense ID.
Offense ID	Distinct identifier to denote when there are multiple offenses associated with a single report.
Offense Start	Start date and time the offense(s) occurred.
Offense End	End date and time the offense(s) occurred, when applicable.
Report Date	Date and time the offense(s) was reported. (Can differ from date of occurrence)
Group A B	Corresponding offense group.
Crime Against Category	Corresponding offense crime against category.
Offense Parent Group	The parent group of the offense.
Offense	The offense carried out in the crime.
Offense Code	Corresponding offense code.
Precinct	Designated police precinct boundary where offense(s) occurred.
Sector	Designated police sector boundary where offense(s) occurred.
Beat	Designated police sector boundary where offense(s) occurred.
MCPP	Designated Micro-Community Policing Plans (MCPP) boundary where offense(s) occurred.
100 Block Address	The offense (s) address location blurred to the one hundred block.
Longitude	Offense(s) spatial coordinate blurred to the one hundred blocks.
Latitude	Offense(s) spatial coordinate blurred to the one hundred blocks.

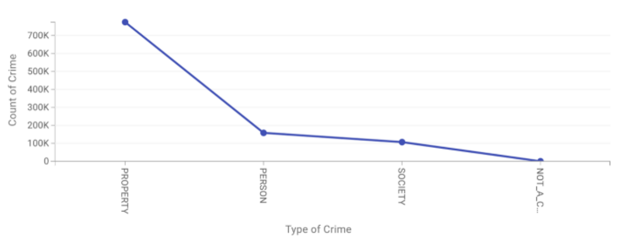

Fig. 1. Crimes against category.

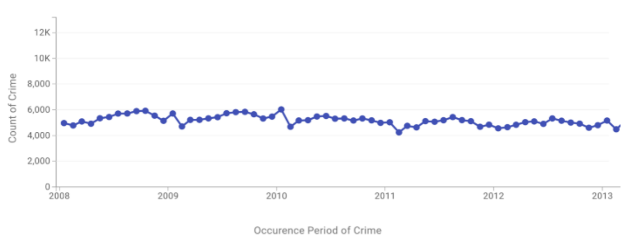

Fig. 2. Crimes against year.

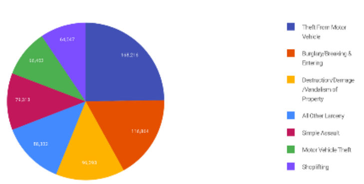

Fig. 3. Types of crimes.

Fig. 1 shows that the number of crimes against the property exceeds 700K, and Fig. 2 shows that the number of crimes in the city fluctuates between 4000 and 6000 crimes.

B. 911 Incident Response

We have retrieved the 911 incident response data and will review the crime dataset's columns. This dataset, represented in Table II, provides an in-depth look at crime incidents in Seattle, detailing further information on the incident.

TABLE II. 911 INCIDENT RESPONSE DATASET

Column Name	Column Description
CAD	Computer-Aided Dispatch is a software system used by police dispatchers to receive and process 911 calls. CAD ID identifies the calls.
CDW ID	Crime Data Warehouse Identifier is a unique identifier assigned to each incident reported to the Seattle Police Department.
CAD Event Number	The event number associated with the CAD
General Offense Number	The corresponding offense number.
Event Clearance Code	Event Clearance Code refers to the status of an incident after the police have responded to it.
Event Clearance Description	Corresponding description.
Event Clearance SubGroup	Corresponding sub-group of the incident.
Event Clearance Group	Corresponding group of the incident.
Event Clearance Date	The date on which the incident was cleared.
Hundred Block Location	The offense (s) address location blurred to the one hundred blocks.
District/Sector Zone/Beat	Corresponding zone of the incident.
Census Tract	The occurrence incident occurred within a specific census tract.
Longitude	The longitude of the event location.
Latitude	The latitude of the event location.
Incident Location	The corresponding event location.
Initial Type Description	The initial type description of the event location.
Initial Type Subgroup	The initial type subgroup of the event location.
Initial Type Group	The initial type group of the event location.
At Scene Time	The time at which the officer responded to the scene

VIII. RESEARCH FINDINGS AND DISCUSSION

Our proposed method, along with the Random Forest algorithm, can be used to predict areas where crimes are likely to take place. Consequently, a score can be assigned to each city location, indicating the probability of a crime occurring in that area [8]. As a result, police resources can be deployed more productively, and preventive measures can be taken more effectively. Subsequently, after the initial hotspots have been identified, patrol units can be directed toward the most suitable patrol routes. Such routes are selected using a greedy algorithm that maximizes the patrol unit presence close to the hotspots. Furthermore, the records associated with each node are exclusively dependent on the criminal history that has taken place in that specific node. This approach does not change the route plan based on a dynamic emergency call. However, we consider dynamic emergency calls that might come in. Finally, a hamilton path is created based on the hotspots and emergency call nodes while considering the dynamically updated hotspots [9].

The development of the suggested method started with a thorough evaluation of various algorithms appropriate for optimizing police patrol routes in real-time. Following a thorough analysis of recent research and methodologies, it was determined to make use of both random forest and ravenous computations [8]. Although the ravenous calculation was chosen for its suitability in optimizing patrol routes using the most recent crime information, the random forest was chosen for its ability to manage large datasets and intricate relationships between factors. Later, a number of intricate procedures were included in the information preprocessing organization to guarantee the accuracy and quality of the dataset. This involved removing anomalies or outliers from the data and creating current highlights to gather useful information for course optimization.

A thorough validation process was carried out to ensure the proposed method's accuracy and reliability. A validation dataset comprising authentic crime information from a representative urban range was chosen for intensive investigation. This dataset was chosen to include a wide variety of crime occurrences, including different crime categories and geographic regions [8]. A set of assessment measurements was utilized to survey the proposed method's execution. These metrics—accuracy, accuracy, review, and F1-score—offered numerical evaluations, assessments, and appraisals of how well the method anticipated crime hotspots and optimized patrol routes. In arranging to set up a standard by which to degree the execution of the recommended procedure, the validation was too different from those of other approaches. This comparative analysis made the focal points and impediments more clear.

The efficacy and performance of the suggested methodology were assessed by contrasting it with current practices. The effectiveness of various techniques, including static patrol route planning and conventional random routing, in identifying crime hotspots and maximizing patrol routes was evaluated [8]. The comparative analysis demonstrated that the suggested methodology exhibited superior performance compared to conventional methods concerning precision, efficacy, and overall crime prevention outcomes. The suggested methodology was shown to be superior in real-time police patrol route optimization by this comparative analysis, which also offered insightful information about the advantages and disadvantages of various approaches.

IX. Conclusion

Crime is a primary setback that every country must address before it becomes problematic to society. With proper patrol services, the security sector can curb the offender's activities that often threaten economic growth and well-being. The well-thought placement of officers has been deemed one of the strategies that can help the sector realize its long-term security goals. Also, having proper and advanced techniques can provide real-time information on criminal activities. This is of the essence as it helps the responsible officers to take charge of the needed actions. This is also a resource-friendly tactic, ensuring the sector stays within the budget. While the method has been used to cater to the security needs in society, it is still not the most ideal as it is associated with some limitations, such as a randomized method in choosing the problem areas, leaving out some areas that might be affected more than the ones selected. The spatial selection method has been regarded as the method that can rule out the limitations linked to the randomized analysis of the problem areas. Policing must be efficient as it aims to attain its intentions. Modern advances have acted as a stepping stone for the key players to make the needed decisions on the ideal techniques that can help all the concerned players. The public, the sole beneficiary, must also be informed on the key issues that aid the processes. Most operations and activities depend on the nature of the countries' security. Investors, for instance, must be keen on the nature of the security before investing in their preferred ventures. The fact that they are interested in the overall outcomes means they must properly conduct reconnaissance to identify the loopholes that can disadvantage them in the long term.

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