Spatio-Temporal Patterns Analysis of Road Accidents in Butuan City Using Geographic Information System (GIS)

Jayson V. Jamelo
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

Christian Joe F. Saldia
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

Eric Dave D. Doria
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

Arnaldo C. Gagula
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

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Jayson V. Jamelo[1], Christian Joe F. Saldia[1], Eric Dave D. Doria[1,2], Arnaldo C. Gagula[1,2]
[1]Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University
[2]Caraga Center for Geo-informatics, Caraga State University
Corresponding author email: acgagula@carsu.edu.ph

Abstract: *This study investigates the spatiotemporal patterns of road accidents in Butuan City from 2019 to 2022 using Geographic Information System (GIS) techniques. The research aims to identify accident hotspots. Through spatial autocorrelation and statistical analysis tests, the study reveals significant clustering of accidents along specific road segments, highlighting areas with higher accident rates. The findings provide valuable insights for traffic managers and decision-makers, enabling them to implement targeted interventions to improve traffic safety in Butuan City. Additionally, the study employs statistical tests to determine the association and strength of relationships between various factors influencing road accidents, offering a comprehensive analysis of the underlying causes and spatial distribution of accidents in the city. This research contributes to a better understanding of road accident patterns in Butuan City, providing a basis for developing effective road safety measures.*

Keywords: Road Accidents, Spatial Autocorrelation, GIS, Statistical Test

1. INTRODUCTION

In today's world, transportation is essential for people's daily lives, especially in Butuan City, which is experiencing modernization. With a rapidly growing economy, the Philippines has witnessed a significant increase in car sales annually, one of the fastest rates in the ASEAN region, without a corresponding investment in sustainable urban transport infrastructure or road space. From 2007 to 2012, car ownership rose by 16%, while motorcycle ownership surged by 69% [1]. The rising number of cars correlates with an increased risk of traffic accidents. The World Health Organization predicts that with growing urbanization and motorization, road fatalities are likely to become the fifth-leading cause of death by 2030 [2].

Traffic accidents pose a major global challenge due to their severe impact on human life, the economy, and society. In the Philippines, the increasing number of road accidents highlights the need for thorough research to identify causes and implement effective measures to improve road safety. Each year, approximately 1.35 million people worldwide lose their lives in road traffic accidents [3]. Those residing in high-density areas are prone to road accidents because they tend to travel longer to reach their desired destination [4]. Existing literature has highlighted the role of drivers' safety measures in the increase of road accidents. However, addressing this issue requires more than just relying on drivers. Despite recent studies identifying the causes of road accidents, the literature must also pinpoint accident-prone areas and provide insights into the safety measures needed to reduce accidents. Identifying these high-risk areas is crucial for developing targeted interventions to mitigate accidents. Conducting a spatial-temporal analysis in these areas can effectively evaluate the effectiveness of implemented safety measures. Recent literature emphasizes the importance of Geographic Information Systems (GIS) as a critical tool for analyzing road accidents and road design, offering valuable insights for preventing traffic accidents. GIS can effectively determine the relative rates of vehicular accidents, indicating a higher level of safety regarding reduced incidents and enhanced safety measures [5].

Geographic Information Systems (GIS) have become widely recognized globally as a valuable tool for managing transportation resources, enhancing operational efficiency, and improving preventive measures. GIS technology enables traffic agencies to visualize accident data, pinpoint high-risk areas, and facilitate informed decision-making [6]. GIS can identify suitable areas for specific purposes, which is helpful in spatial analysis [7]. This study aims to examine the spatial-temporal patterns of road accidents in Butuan City using GIS and statistical analysis. The goal is to offer valuable insights and recommendations for understanding and improving road safety in Butuan City. However, it is crucial to recognize that limitations in data availability and modeling constraints may impact the interpretation of the study's findings due to its complexity. Road accidents cause significant social and economic harm. By analyzing datasets related to accident occurrences, peak accident times, and factors contributing to accidents, such as weather conditions at the time of the incident, valuable insights can be gained to understand and address these issues comprehensively [5].

The primary objectives are to analyze the spatial-temporal patterns of road accidents in Butuan City using GIS and to determine significant factors contributing to road accidents, recommending interventions to improve road safety measures using statistical analysis techniques. Through GIS, traffic agencies can deepen their comprehension of transportation dynamics, enabling the implementation of focused interventions to reduce potential risks and enhance overall safety [6]. The statistical test will be employed to ascertain the causes of road accidents, establishing a relationship between road accidents and the factors that require attention. Butuan City in the Philippines is an urban area grappling with increasing road accidents and related fatalities. Statistics indicate a troubling rise in car accidents, nearly doubling over time. This trend underscores the pressing need for a comprehensive approach to road safety in Butuan City. A statistical test examines the correlation between pedestrian injury severity and accidental morphological parameters in pedestrian-vehicle accidents [6]. This study utilizes correlation analysis to examine the relationship between an independent variable and various factors that may contribute to road accidents. Statistical tests help establish correlations by identifying relationships between these factors and the occurrence of accidents. They assess risk factors, such as the correlation between poor lighting and increased accidents at night and can forecast future accident patterns based on past data. This knowledge informs the development of policies and interventions, allowing authorities to implement targeted measures, such as stricter speed enforcement, to enhance road safety [8].

2. METHODOLOGY

2.1 Study Area

Butuan City, located in the Caraga Region of the Philippines, served as the study area for this research. With a population of approximately 372,910 [9]. Butuan City has been experiencing rapid growth and development, accompanied by challenges in road safety. Despite the city's rapid growth and development, there have been persistent challenges in ensuring road safety. These challenges include inadequate infrastructure, traffic congestion, and insufficient enforcement of traffic rules. As a result, road accidents continue to pose a significant concern for residents and commuters in Butuan City.

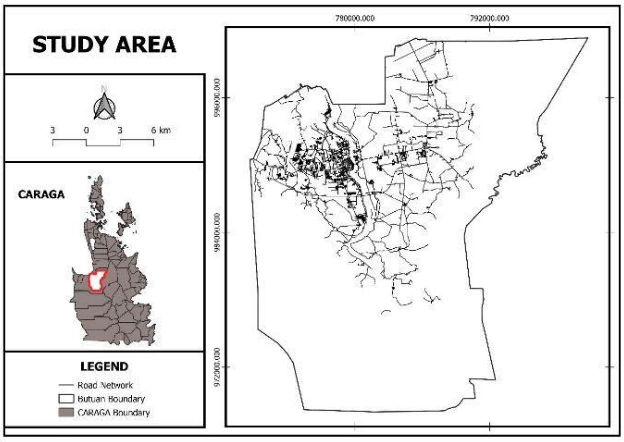

Fig. 1. Map of Butuan City.

2.2 Data Collection and Preparation

Data collection for this study involved gathering relevant information on road accidents in Butuan City. The primary source of data was the Caraga Center for Geo-Informatics (CCGEO), Department of Public Works and Highways (DPWH), National Police Commission (NAPOLCOM) and Butuan City Police Office (BCPO), which provided records of accidents, including their locations and types. In 2019, 757 accidents were reported, followed by 492 in 2020, 560 in 2021, and 711 in 2022 according to NAPOLCOM which is the mandated agency to administer and control the Philippine National Police.

2.3 Spatial Analysis of Road Accidents

2.3.1 Kernel Density Estimation

Kernel Density Estimation (KDE) is a statistical technique used to estimate the probability density function of a continuous random variable based on a set of observed data points [10]. KDE is particularly useful for identifying areas of high concentration or "hotspots" of events, such as road accidents. Researchers apply KDE to create a continuous surface representing the density of accidents across a Butuan. By visualizing these hotspots, authorities can make informed decisions regarding targeted safety measures and infrastructure improvements. The general formula for Kernel Density Estimation was as follows:

$$\hat{f}(x,h) = \frac{1}{N}\sum_{i=1}^{N} K_H(x - x_i)$$

Equation 1

The variable *f(x, h)* represents the estimated density function. The variable *N* stands for the number of data points in the dataset. Each data point in the dataset was denoted by *xi*. The kernel function, a non-negative function, was represented by *KH*. Lastly, *H* was a smoothing parameter known as the bandwidth. This bandwidth played a crucial role in KDE as it determined the width of the kernel function [11].

2.3.2 Moran's I Global Autocorrelation

Moran's I global autocorrelation method was employed in this study to assess the spatial patterns of road accidents in Butuan City. Moran's I quantified the degree of spatial autocorrelation by measuring the similarity of attribute values between neighboring locations. The general formula for Moran's I was as follows:

$$I = \frac{n}{\sum_i \sum_j w_{ij}} x \frac{\sum_i \sum_j w_{ij}(x_i - \underline{x})(x_j - \underline{x})}{\sum_i (x_i - \underline{x})^2}$$

Equation 2

In this formula, *n* represents the total number of locations, *xi* and *xj* are the attribute values at locations *i* and *j*, respectively, $\bar{x}$ denotes the mean attribute value, and *wij* represents the spatial weight between locations *i* and *j*. The spatial weights (*wij*) can be defined based on distance, contiguity, or other spatial relationships. Positive values of Moran's indicate positive spatial autocorrelation (clustering), while negative values suggest negative spatial autocorrelation (dispersion) [11].

2.3.3 Getis-Ord Gi*

This study employed Hotspot Analysis using Getis-Ord Gi* to examine the spatial distribution of road accidents in Butuan City. Getis-Ord Gi* is a statistical measure that identifies statistically significant clusters (hotspots) of high or low attribute values in a spatial dataset. The general formula for Getis-Ord Gi* was as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \underline{x}\sum_{j=1}^{n} w_{ij}}{s\sqrt{\frac{(n\sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} w_{ij})^2)}{n-1}}}$$

Equation 4

Where *Gi** represents the Getis-Ord Gi* statistic for location *i*, *xj* is the attribute value at location *j*, $\bar{x}$ is the mean attribute value, *wij* is the spatial weight between locations *i* and *j*, and *s* is the standard deviation.

This study leveraged the Getis-Ord Gi* statistics to pinpoint spatial clusters of high (hotspots) or low (coldspots) accident occurrences. By analyzing neighboring accidents, positive Gi* values indicated hotspots, while negative values suggested coldspots.

2.3.4 Pearson Correlation Analysis

Pearson Correlation was employed to ascertain the correlation between the Getis-Ord Gi* analysis results and various variables. Pearson is a statistical method utilized to determine the degree of association between variables, allowing for examining potential spatial dependencies or spatial relationships within the dataset. This analysis aimed to understand whether the observed spatial patterns identified by the Getis-Ord Gi* statistic were significantly associated with specific explanatory variables.

The Pearson Correlation r calculated using the formula:

$$r = \frac{n(\Sigma \quad xy)-(\Sigma \quad x)(\Sigma \quad y)}{\sqrt{[n(\Sigma \quad x^2)-(\Sigma \quad x)^2][n(\Sigma \quad y^2)-(\Sigma \quad y)^2]}}$$

Equation 5

In this formula, x and y represent the values in the first and second data sets, respectively, n is the total number of values, and Σ represents the summation of all values. It's important to note that while the Pearson correlation coefficient can tell you about the strength of an association, it does not measure the significance of the association. The values of r range from -1 to +1. A r value of -1 means the variables have a perfect negative linear relationship, a r value of +1 means the variables have a perfect positive linear relationship, and a r value of 0 means no linear relationship between the variables [10] [12].

3. RESULTS AND DISCUSSIONS

3.1 Kernel Density Estimation

Kernel Density Estimation (KDE) was employed to discern the areas characterized by both high and low concentrations of road accidents. Figure 2 represents a sample distribution of road accidents in Butuan City in the year 2022. The darker shades of red indicate areas with a higher concentration of accidents while lighter color indicates the opposite. The map covers the roads of JC Aquino Avenue, Butuan City.

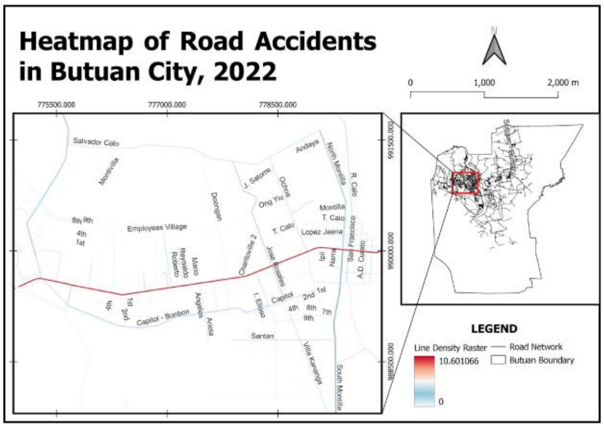

Fig. 2. Kernel Density Map for the year 2022.

3.2 Spatial Autocorrelation (Global Moran's I)

Spatial autocorrelation graph illustrating the z-score and p-value of road accidents occurring between 2019 and 2022 in Butuan City, utilizing Moran's I statistics. In Table 1, the Moran's I value for the years 2019 through 2022 were 0.012464, 0.061935, 0.046484, and 0.079994, accompanied by z-scores of 13.346219, 4.738709, 3.420183, and 6.774542, and corresponding p-values of 0.000000, 0.000002, 0.000626, and 0.000000 respectively. These results indicate a statistically significant status, specifically a densely clustered pattern, as evidenced by the positive Moran's I values, high z-scores, and small p-values, suggesting that road accidents were spatially clustered, with less than a 1% likelihood of this clustered pattern occurring by random chance.

Table 1. Summary of Global Moran's Autocorrelation from the year 2019 – 2022

Year	Moran's Index	z-score	p-value	Indication
2019	0.012464	13.346219	0.000000	Clustered
2020	0.061935	4.738709	0.000002	Clustered
2021	0.046484	3.420183	0.000626	Clustered
2022	0.079994	6.774542	0.000000	Clustered

3.3 Hotspot Analysis Using Getis–Ord Gi*

Figure 3 and Table 2 summarize road accident data in Butuan City for 2019, categorized by confidence levels. Out of 753 accidents, 110 were identified with a 99% confidence level, rated as high, and predominantly occurred on JC Aquino Avenue, Butuan City. At the 95% confidence level, 77 accidents were identified and rated as medium, primarily occurring on JC Aquino Avenue, Butuan City. Finally, at the 90% confidence level, 30 accidents were identified and rated as low, with JC Aquino Avenue, Butuan City, remaining the dominant location for these incidents.

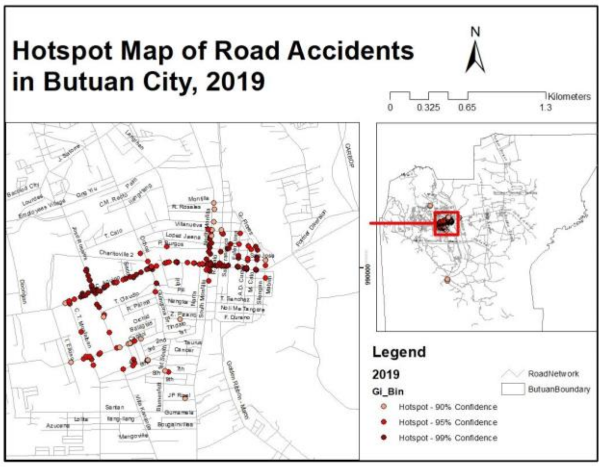

Fig. 3. Hotspot based on 99%, 95% and 90% Confidence in 2019.

Table 2. Number of Accidents in 2019 based on Confidence and the Dominant Road Segment

Confidence	Total Number of Accidents	Number of points in 2019	Dominant at
99%	753	110	JC Aquino
95%	753	77	JC Aquino
90%	753	30	JC Aquino

Road accident data in Butuan City for 2020, organized by confidence levels and ratings based on the number of points relative to the total number of accidents. Out of 492 accidents, 41 points were identified with a 99% confidence level, rated low. At the 95% confidence level, 45 points were identified, also rated low. Finally, at the 90% confidence level, 44 points were identified, maintaining a low rating. JC Aquino Avenue, Butuan City, was the dominant location for these incidents.

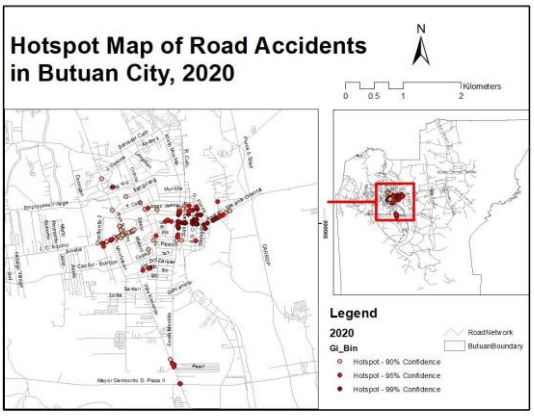

Fig. 4. Hotspot based on 99%, 95% and 90% Confidence in 2020.

Table 3. Number of Accidents in 2020 based on Confidence and the Dominant Road Segment

Confidence	Total Number of Accidents	Number of points in 2020	Dominant at
99%	492	41	JC Aquino
95%	492	45	JC Aquino
90%	492	44	JC Aquino

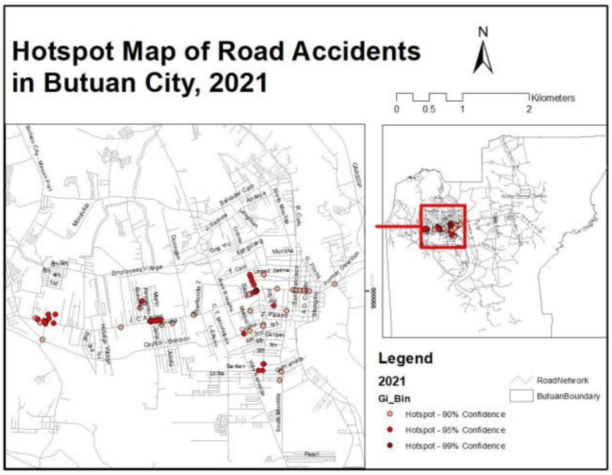

Fig. 5. Hotspot based on 99%, 95% and 90% Confidence in 2021.

Out of 560 accidents, 10 points were identified with a 99% confidence level, rated as very low, and predominantly occurred on JC Aquino Avenue. At the 95% confidence level, 42 points were identified, rated as low, with most accidents also occurring on JC Aquino Avenue. At the 90% confidence level, 35 points were identified, maintaining a low rating, with JC Aquino Avenue remaining the dominant location for these incidents.

Table 4. Number of Accidents in 2021 based on Confidence and the Dominant Road Segment

Confidence	Total Number of Accidents	Number of points in 2021	Dominant at
99%	560	10	JC Aquino
95%	560	42	JC Aquino
90%	560	35	JC Aquino

Out of 502 accidents, 57 points were identified with 99% confidence, rated as medium, and predominantly occurred on JC Aquino Avenue. At the 95% confidence level, 84 points were identified and rated as high, with most accidents also happening on JC Aquino Avenue. Finally, at the 90% confidence level, 36 points were identified, rated as low, and JC Aquino Avenue remained the primary location for these incidents.

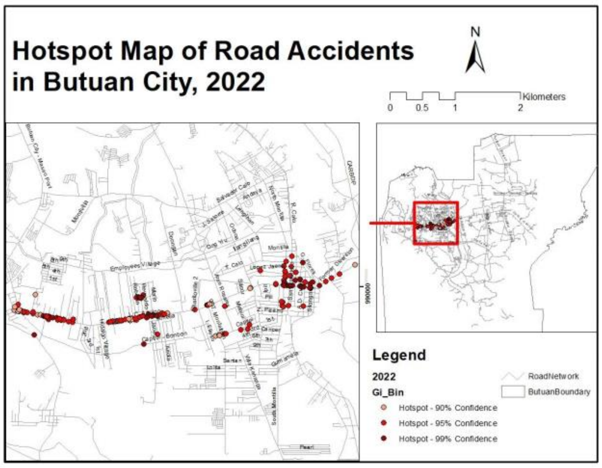

Fig. 6. Hotspot based on 99%, 95% and 90% Confidence in 2022.

Table 5. Number of Accidents in 2022 based on Confidence and the Dominant Road Segment

Confidence	Total Number of Accidents	Number of points in 2022	Dominant at
99%	502	57	JC Aquino
95%	502	84	JC Aquino
90%	502	36	JC Aquino

3.4 Pearson Correlation Analysis

Table 6. Pearson Correlation Insignificant

Parameters	r	df	t	p value
Road Accidents vs Weather Conditions	-0.5309	4	1.2529	0.1392
Road Accidents vs Road Condition	-0.9665	3	3.7665	0.0826
Road Accidents vs Traffic Lights	-0.6191	4	-1.5766	0.0950

Table 6 presents the Pearson correlation analysis between road accidents and three variables: weather conditions, road conditions, and traffic lights. These variables' correlation coefficients (r) were -0.5309, -0.9665, and -0.6191, respectively. With p-values of 0.1392, 0.0826, and 0.0950, these correlations were statistically insignificant, suggesting no strong linear relationship between these factors and road accidents within the studied sample.

Table 7. Pearson Correlation Significant

Parameters	r	df	t	p value
Road Accidents vs Volume in pcu/hr	0.7420	4	2.2135	0.0456
Road Accidents vs Pedestrian Lanes	-0.9088	4	-4.3563	0.0060

Road Accidents vs Traffic Signages	-0.8277	4	-2.9496	0.0210

Table 7 shows the significant Pearson correlations between road accidents and three parameters: traffic volume, pedestrian lanes, and traffic signages. These variables' correlation coefficients (r) were 0.7420, -0.9088, and -0.8277, respectively. P-values of 0.0456, 0.0060, and 0.0210 indicate statistically significant relationships. These findings imply that increased traffic volume positively correlates with road accidents, while the presence of pedestrian lanes and traffic signages negatively correlates with road accidents, highlighting their potential protective effects.

Table 8. Pearson Correlation (Behavioral and Psychological Factor/s) Insignificant

Parameters	r	df	t	p value
Road Accidents vs Over speeding	0.5343	4	1.2641	0.1374

Table 8 shows the Pearson correlation analysis between road accidents and over speeding. The correlation coefficient (r) was 0.5343, with a p-value of 0.1374. This result suggests an insignificant correlation, indicating that over speeding does not have a statistically significant linear relationship with the frequency of road accidents in this study.

Table 9. Pearson Correlation (Behavioral and Psychological Factor/s) Significant

Parameters	r	df	t	p value
Road Accidents vs Drunk Driving	0.9275	4	4.9634	0.0038
Road Accidents vs Reckless/Distracted Driving	0.9649	4	7.3433	0.0009
Road Accidents vs Sudden Overtaking	0.8623	4	3.4060	0.0136

Table 9 details the Pearson correlation analysis for significant behavioral and psychological factors related to road accidents. The correlation coefficients (r) for drunk driving, reckless/distracted driving, and sudden overtaking were 0.9275, 0.9649, and 0.8623, respectively. The p-values of 0.0038, 0.0009, and 0.0136 demonstrate significant correlations, underscoring that these behaviors are strongly associated with an increased risk of road accidents. These findings highlight the critical impact of driver behavior on road safety.

4. CONCLUSIONS AND RECOMMENDATIONS

The findings revealed a clustered relationship between accident locations and their severity, with significant clustering tendencies around the J.C. Aquino area. The use of Local Moran's Autocorrelation identified areas in Butuan City with low and high outliers surrounded by low and high clusters, with most areas exhibiting clustering tendencies around the J.C. Aquino area. Getis-Ord Gi* analysis indicated a higher likelihood of clustering in the data, particularly in 2019, with 99% confidence. The correlation analysis between accident hotspots and the reasons for road accidents showed varying degrees of association over the years, with 2022 exhibiting a significant relationship in volume in pcu/hr, pedestrian lanes, and traffic signages and the behavioral and psychological factors which are drunk driving, reckless/distracted driving, and sudden overtaking. These findings provide valuable insights for implementing interventions and improving road safety measures to reduce the frequency and severity of road accidents in Butuan City.

The study recommends expanding correlation studies to include factors such as the driver's physical and mental condition, driver's experience level, road characteristics (curves, intersections, blind spots, gradients), visibility and effectiveness of traffic signage, traffic flow patterns, adequacy of road safety measures, and density of the road network. Developing a comprehensive model to analyze the impact and effectiveness of various preventive measures is also suggested to help policymakers prioritize and implement the most effective interventions.

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