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THEORY AND APPLICATIONS OF CRIME SITUATION AWARENESS TECHNOLOGY

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Abstract: Crime situation awareness technology utilizes crime big data to analyze the patterns and trends of criminal incidents, predict potential future crimes, and promote the transformation of public safety towards proactive prevention. It provides decision-making support for public security such as risk management and police resource allocation. The paper presents a comprehensive review of crime situation awareness and summarize the general process. Based on theories and algorithms, the review is categorized into methods based on criminal theories, machine learning, and deep learning. Additionally, it conducts an in-depth analysis of the limitations of existing methods and proposes three potential research directions: basic theories of crime situation awareness, crime situation awareness technology models, and crime situation awareness intelligence decision-making.
Keywords: Crime situation awareness; Criminal theory; Machine learning; Deep learning

1 INTRODUCTION

The modern social governance model should adhere to the principle of safety first and prevention first, establish a framework for comprehensive safety and emergency response, improve the public safety system, and promote the transformation of public safety governance model towards pre-emptive prevention. At present, the social security situation is still complex and severe, and various crimes such as burglary, telecommunications fraud, and online gambling continue to occur frequently, making the passive policing model based on investigation and crackdown difficult to meet the actual needs of public security work. Therefore, it is of great significance to rely on situational awareness technology to conduct in-depth mining of crime data, comprehensively grasp the public security situation, and enhance the ability to warn and prevent crime risks, maintain social stability, and realize the modernization of social governance capabilities.

Situation awareness technology is a method based on big data security, which enhances the ability to detect, understand, analyze, respond to, and handle security threats from a holistic perspective. Crime situational awareness technology is the scientific use of crime data to deeply analyze the spatial and temporal patterns and trends of crime events, predict possible future crime events, and provide decision support for public security work such as public security risk prevention and control, police resource scheduling, and so on. Early situational awareness methods mostly relied on specific criminological theories for analysis, such as the theory of daily activities [3], which defines crime as the result of the interaction of criminals, potential targets, and regulatory states in a specific space. The relevant methods are based on criminological theories, and include the construction of evaluation indicators and risk assessment models for potential offenders, community physical environments, and protective measures [4]. With the rapid development of information technology, the total amount of crime-related data is becoming increasingly large and the sources are more extensive, making high-performance data mining algorithms gradually become the mainstream of situational awareness technology [5]. For example, using historical crime data to train a crime situational awareness data model, and predicting future crime trends through existing data information and popularity; Through clustering analysis of crime data, potential similarities and correlations between different cases can be explored.

In summary, this article provides a comprehensive overview of crime situational awareness technology, with three contributions.

- Summarizing the general process of crime situational awareness technology.
- Propose a new classification method for crime situational awareness technology, which is divided into methods based on criminological theory, machine learning, and deep learning according to their principles.
- Conduct a systematic analysis and review of existing crime situational awareness technologies to understand the principles and applications of existing technologies.
- Prospect the future research direction of crime situational awareness technology.

2 CRIME AWARENESS PROCESS

Crime situation perception is the comprehensive perception and assessment of the overall situation of criminal activities through various data sources and analysis methods, in order to better carry out crime governance work. Typically, crime situational awareness generally includes the following steps:

2.1 Acquisition of Crime Data

Crime data sources are mainly divided into two aspects: (1) Internal data from police departments, such as police call records (including confidential information like case types, time of occurrence, location, participants, etc.) and urban surveillance videos; (2) Open-source external data, such as public information on government websites and user data on

social networking platforms. Since crime data often involves public safety and personal privacy issues, it is crucial to avoid illegal disclosure of relevant information during the acquisition process and to ensure proper data desensitization is carried out.

2.2 Crime Data Preprocessing

Crime data preprocessing involves converting the collected raw crime data into a format that is recognizable and storable by computers. This includes, for example, removing useless information such as data noise, correcting errors in characters and timestamps within the data, identifying and deleting duplicate records, and handling missing values. In addition, to improve data storage efficiency, data standardization operations are necessary, encompassing format unification (aligning information such as time and location), data encoding, data conversion, and data verification.

2.3 Crime Data Feature Engineering

Feature engineering involves transforming the preprocessed crime data by extracting and retaining specific information based on specific analysis tasks. For instance, the open-source data Chicago Crime Data [6] contains crime records from the Chicago Police Department's CLEAR system since 2001 (excluding murders), with 22 field features such as case number, date, latitude and longitude, crime type, community, arrest status, etc., to describe each crime event. Good feature engineering not only enhances the predictive performance of situational awareness technologies but also improves the interpretability of the perception results.

2.4 Analysis of Crime Data

Crime data analysis is a process of analyzing and interpreting crime-related data using criminological theories, data mining, machine learning, and other technical means. The core objectives are to identify crime patterns and perceive crime trends, assess the risk levels of crime events, determine the basic types of crime events, and predict potential criminal activities. By analyzing crime data, public security organs can more effectively allocate policing resources, formulate community and street security strategies, and enhance the level of urban public safety governance and urban resilience.

3 CRIME AWARENESS TECHNOLOGY

At present, research on crime situational awareness technology has made some progress, and many research results with great reference significance and high value have been formed. This section is divided into methods based on criminological theory, machine learning, and deep learning according to the theories and algorithms of different technology applications.

3.1 Method based on criminological theory

Classic criminological theories provide important theoretical support for situational awareness, such as the theory of daily activities, which suggests that crime is the result of the interaction of criminals, potential targets, and regulatory states in a specific space, and is associated with specific physical environments. The theory of crime patterns suggests that crime is most likely to occur in areas where the activity spaces of both perpetrators and victims overlap. Based on the above theory, Zhao Ziyu et al. [7] conducted an in-depth analysis of pickpocketing cases in Changchun City, and concluded that the spatial pattern of pickpocketing cases is proximity predation, which means that the high-incidence areas of pickpocketing and the main residential areas of criminals are highly overlapping in physical space, and there is a significant spatial attenuation effect. At the same time, based on existing case data, it is inferred that the crime buffer zone is roughly located 2 km away from the residence of the perpetrator. Zhao Pengkai and others used community property-related public security cases to reveal the risk sources of community property-related cases, and constructed evaluation indicators including potential perpetrators, potential victims, community physical environment, and protective measures. They determined the weight coefficients of indicators at all levels through the analytic hierarchy process [8], among which the high proportion of migrant population in the community, high coverage of technical defense, and high guard at community entrances and exits have a greater impact on property-related crimes. Based on the theory of environmental criminology and population and environmental factors, Chen Peng and others constructed a hierarchical model and evaluation index system for community burglary cases [9]. The weight of each indicator is shown in Table 1. From the results, the main factors affecting burglary cases are the proportion of migrant population and preventive measures. The method based on criminological theory relies on researchers to integrate theoretical knowledge of crime and typical cases, in order to discover the patterns and trends of crime.

3.2 Methods Based on Machine Learning

Research on machine learning-based methods explores how to use computers to obtain potential information contained in crime data, involving feature processing, situational awareness models, and other content. Sun Feifei and others extracted common characteristics of criminals in criminal cases from multiple dimensions such as life trajectory, growth experience, views on life, and ethical and moral concepts, forming a criminal personality profile. Then, they mapped the characteristics to a random forest to classify simulated criminal samples and perceive the criminal tendencies of key individuals [10]. Zhu Xiaobo et al. proposed the PSO-BP method to improve the sensitivity to initial weights and the tendency to fall into local optima in the analysis of crime data using traditional BP neural networks. By introducing the particle swarm optimization algorithm PSO to globally search and optimize network weights, the PSO-BP method can

effectively address these issues. In the experiment of predicting the number of theft crimes in Chicago, the PSO-BP neural network model significantly improved the prediction accuracy compared to the BP model, with the relative error reduced from 4.68% to 1.635%. Wang Juan and others have added analysis of environmental factors in crime areas, using ensemble learning methods [12] to mine the main environmental factors of crime and predict regional risk levels [13]. They have identified a temporal distribution pattern for robbery-related crimes, which occur most frequently around 6 pm and 10 pm in the evening, and more frequently in summer than in other seasons, with a certain periodicity. In addition, when Wang Juan and others conducted a classification prediction experiment on the criminal risk areas of robbery-related crimes, the ensemble learning model had the best classification effect, with an accuracy rate of over 90%.

Table 1 Risk Assessment Criteria Weight Allocation [9]

First-level indicators		Second-level indicators	
Personnel（B1）	0.4286	Proportion of floating population（C1）	0.3214
		Per capita income level（C2）	0.1071
Environment（B2）	0.1429	Community openness（C3）	0.0476
		Building security（C4）	0.0476
		Remoteness of community location（C5）	0.0476
Prevention（B3）	0.4286	Coverage of technological prevention measures（C6）	0.1837
		Proportion of human prevention forces（C7）	0.0612
		Propaganda intensity for community theft prevention（C8）	0.1837

3.3 Methods Based on Deep Learning

Deep learning is a new research direction in the field of machine learning, which can learn the inherent rules of sample data more deeply. Shen Hanlei and others used an improved recurrent neural network, Recurrent Neural Network, RNN - Long Short-Term Memory Network, LSTM model to construct a binary alarm data long short-term memory model BD-LSTM and a frequency statistics data long short-term memory model RD-LSTM to predict the probability and number of cases occurring in each region [14]. In practice, Shen Hanlei and others used the data of burglary cases in the 110 alarm data of WH City from 2015 to 2018 to train the BD-LSTM and RD-LSTM models, effectively predicting the occurrence probability and number of burglary cases in various areas of WH City, with high accuracy and stability. Wei Dong and his team used deep neural networks and Mnd-Knox algorithm to capture the density of crime behavior in the microscopic scale, and visualized the results as a crime hotspot information map to guide the allocation of police resources [15]. Zhai Shengchang and others proposed a BP neural network model ARIMA-GRU that comprehensively considers factors such as season, time correlation, spatial correlation, holidays, and temperature to address the difficulty of capturing complex features in crime data. On the real crime dataset of Vancouver, the SARIMA-GRU model can effectively capture the above-mentioned complex features of crime, improving the prediction accuracy of urban remote areas and low-risk areas with fewer crimes [16].

3.4 Discussion

The above research provides important theoretical basis and technical methods for the research of crime situational awareness technology. However, there are still some shortcomings. First, the method based on criminological theory relies on manual analysis and research of crime theories and typical cases. The method is simple and the number of indicators is small, and it lacks analysis of important influencing factors such as spatial and temporal correlation. At the same time, it is limited by the theoretical and operational abilities of staff, and has limited guidance for practical police work; Secondly, methods based on machine learning and deep learning fail to effectively capture the spatiotemporal dependencies of crime data. Most models represent spatial information as grid data and temporal information as sequence data, ignoring the distance information in spatial data and the contextual information of spatiotemporal data during computation; Thirdly, there is a lack of systematic and specialized crime situation perception theory, and a universal crime situation perception theory model has not yet been constructed. There is also a lack of targeted, standardized, and practical risk warning and prevention mechanisms.

4 APPLICATIONS OF CRIME SITUATION PERCEPTION

Crime situational awareness can improve the quality of crime monitoring and prediction through emerging technologies such as big data, artificial intelligence, and the Internet of Things, thereby promoting the construction of public security information and raising the level of public safety governance. In combination with the technologies related to crime situational awareness in Section 3, the application scenarios of crime situational awareness mainly include the prediction of crime hotspots, the prediction of crime frequency, and the prediction of accomplice relationships.

4.1 Prediction of a crime hotspot area

Crime hotspot prediction is a qualitative analysis technique aimed at predicting the spatial distribution of future crime events. First, divide the city map into several regions, then extract crime event features from each region, and then input

these features into machine learning algorithms such as kernel density function or random forest to infer whether the crime rate in each region is a hot spot. The key issues in predicting crime hotspots are the division of spatial regions and the extraction of crime characteristics. These operations directly affect the prediction granularity and accuracy of the model. Through the prediction of crime hotspots, it can not only provide a scientific basis for the public security organs to formulate prevention strategies, but also play an important role in the allocation of police resources, the optimization of patrol routes, and the formulation of community safety policies.

4.2 Prediction of crime frequency

The purpose of crime frequency prediction is to analyze and mine crime time series data through deep learning models such as RNN to predict the frequency of future crimes. By collecting and processing historical crime data, researchers train RNN models to learn and understand the temporal patterns, periodicity, and seasonal changes in crime occurrence, and analyze crime trends. In addition, the RNN-based crime frequency prediction method can effectively handle and capture the time-series dependencies in crime records, and retain the nonlinear features contained in the data, achieving high-precision crime frequency prediction and providing a scientific basis for resource allocation and prevention strategies for law enforcement departments.

4.3 Prediction of the relationship

Prediction of accomplice relationships is a method for identifying potential accomplice connections by analyzing the relational structure of users in social network data. This technique is based on social network analysis theory and utilizes indicators such as node centrality, connectivity, and clustering coefficient to reveal the roles of individuals within the criminal network and their associated patterns. Simultaneously, by constructing and analyzing social network graph structure data and inputting it into graph neural networks or community detection algorithms, it is possible to effectively predict accomplice relationships and identify core members of criminal gangs. In particular, accomplice relationship prediction based on deep learning not only aids in understanding the dynamic structure and operational mechanisms of criminal organizations during intelligence analysis, but also provides technical and decision-making support for public security intelligence analysis and research.

5 FUTURE RESEARCH DIRECTIONS

Crime situational awareness technology is a complex systems engineering that requires a scientific and reasonable architecture design. Although scholars have conducted research on situational awareness and public safety intelligence, a systematic theory has not yet been formed. Additionally, crime data exhibits characteristics such as dynamism, correlation, and uncertainty in both temporal and spatial dimensions, with extremely complex influencing factors, which significantly increases the difficulty of crime data mining and intelligence analysis. Based on this, this section proposes three potential research directions.

5.1 Establishing the Basic Theory of Crime Situational Awareness

Situational awareness technology has facilitated the transformation of crime governance models towards proactive prevention, shifting police work from a reactive mode focused on investigation and crackdown to a proactive mode centered on risk prevention and control. It enables the perception of the spatio-temporal patterns and trends of criminal events, thereby dissolving crime risks at their source. Therefore, it is crucial to clarify the concepts related to crime situational awareness, delineate the scope of research, review regulations, policies, and domestic and international research literature, summarize the progress, advantages, and disadvantages of existing work, analyze current challenges and development trends, and thereby lay a theoretical foundation for the subsequent construction of theoretical and technical models of crime situational awareness, as well as the application of situational awareness technology. Figure 1 summarizes the thinking and process of basic theoretical research on crime situational awareness.

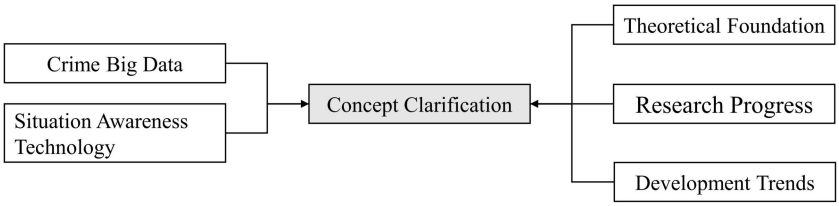

Figure 1 Basic Theories of Crime Situation Awareness

5.2 Enhancing Technical Models for Crime Situational Awareness

Crime data exhibits characteristics such as dynamism, correlation, and uncertainty in both temporal and spatial dimensions, and the factors influencing crime occurrence are also extremely complex, encompassing numerous aspects including population, education level, poverty rate, employment, climate, and more. Most existing situational awareness models represent spatial information as grid data and temporal information as sequence data, neglecting the distance information within spatial data and the contextual association information within spatio-temporal data during computations. To address these issues, we convert criminal factor characteristics, temporal data, and spatial data into spatio-temporal graph data, and construct a crime risk situational awareness model based on spatio-temporal graph representation learning [17]. This model extracts the spatio-temporal dependencies within crime data, improves the

accuracy of crime trend predictions, and generates crime hotspot information maps. Figure 2 summarizes the thinking and process of research on technical models for crime situational awareness.

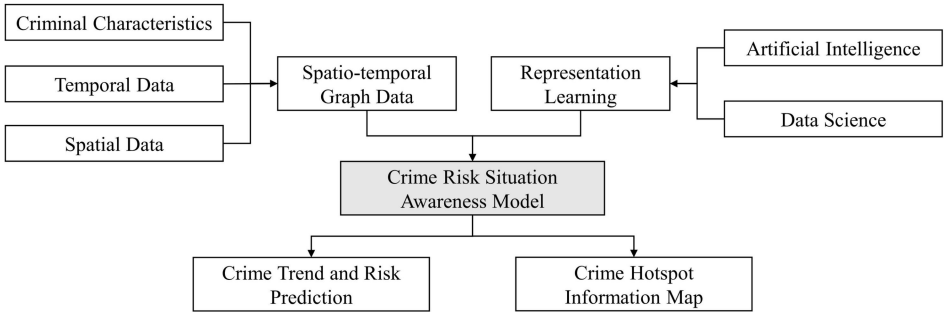

Figure 2 Technical Models of Crime Situation Awareness

5.3 Applying Crime Situational Awareness Technology for Scientific Decision-Making

The application of crime situational awareness technology is based on the fundamental connotation of situational awareness and guided by the results of situational awareness technical models. It tracks the development and evolution of crime risks and promptly pushes security intelligence to decision-makers, thereby enabling accurate and efficient intervention in public safety governance. Crime situational awareness is a complex systems engineering that primarily encompasses three aspects: risk monitoring, decision-making response, and post-event evaluation. Risk monitoring involves tracking the development trends of risks, promptly pushing intelligence to decision-makers, and intervening in public safety governance in a real-time, scientific, and efficient manner. Decision-making response involves adopting scientific and effective measures based on decision-making scenarios, risk evolution pathways, occurrence conditions, and the logical relationships among these conditions, to disrupt the evolution of security risks. Post-event evaluation relies on situational awareness to prevent the occurrence of secondary and derivative events, and carries out damage assessment, event traceback, intelligence evaluation, and other tasks. Figure 3 summarizes the thinking and process of applying crime situational awareness technology for intelligence decision-making.

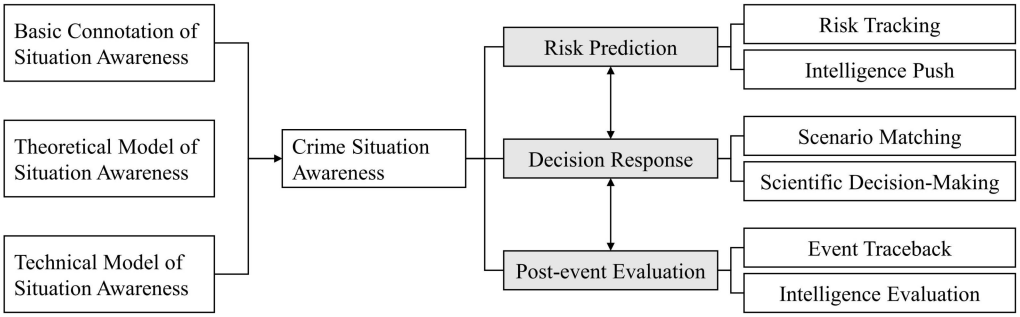

Figure 3 Intelligence Decision-Making for Crime Situation Awareness

6 CONCLUSION

This paper provides a comprehensive review of the literature related to crime situational awareness technology and proposes a classification method for situational awareness technologies. Meanwhile, it conducts an in-depth analysis of the shortcomings of existing methods and suggests three potential research directions. In the face of new social security challenges, public security organs must establish a new policing model supported by big data empowerment, characterized by "professionalism + mechanisms + big data." In future work, it is crucial to fully leverage crime situational awareness technology to facilitate the transition of policing from a reactive mode focused on investigation and crackdown to a proactive mode centered on risk prevention and control. Additionally, relevant models should be utilized to analyze the evolution pathways, occurrence conditions, and logical relationships among various crime risks, providing reference for relevant government decision-making departments and promoting the transformation of public safety governance towards proactive prevention.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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