AI-Assisted Criminal Investigations: Enhancing Testimony Analysis and Case Correlation

Automated Data Collection and Management

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Final Report

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Declaration

I declare that this is my own work, and this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. Also, I hereby grant to Sri Lanka Institute of Information Technology the non-exclusive right to reproduce and distribute my dissertation in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as article or books)

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Karunarathna K. A. D

The above candidate has carried out research for the bachelor's degree Dissertation under my supervision.

Signature of the supervisor: Date:

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Abstract

Criminal investigations traditionally involve manual processing of vast volumes of unstructured data such as police reports, witness testimonies, and incident records, which often results in inefficiencies, human error, and investigative delays. This research addresses these challenges by developing an advanced AI-powered system that leverages Large Language Models (LLMs) and Natural Language Processing (NLP) for automated data collection, testimony analysis, and case correlation in criminal investigations. The system integrates multimodal document processing using an LLM, capable of directly ingesting scanned documents and handwritten notes in multiple languages (English, Sinhala, and Tamil), and extracts structured legal fields into standardized JSON formats. Real-time synchronization with a secure database and an investigator-friendly dashboard support efficient search, filtering, and cross-case analysis, enhancing decision-making accuracy and speed. Pilot testing demonstrates superior accuracy and processing speed compared to traditional OCR and alternative LLM models, validating the technical and operational feasibility of the solution. Furthermore, the system incorporates AI-driven predictive analytics for legal outcome forecasting and emotional-behavioral interrogation support, providing a comprehensive, end-to-end investigative framework. This work bridges key research gaps in multilingual legal document understanding and real-time data-driven criminal case management, offering significant improvements in investigative workflow efficiency, accuracy, and transparency.

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Introduction

1.1. Background

Criminal investigations rely heavily on collecting, organizing, and analyzing large amounts of unstructured data, including police reports, witness testimonies, and incident records. Traditionally, these processes are performed manually, making them highly susceptible to human error, investigator bias, and significant delays in case resolution. Such inefficiencies often result in overlooked evidence, fragmented case handling, and reduced investigative accuracy.

Artificial Intelligence (AI) has emerged as a transformative force in legal and forensic domains. Initial technological integrations focused on Optical Character Recognition (OCR) to digitize physical reports and Natural Language Processing (NLP) to extract structured information. While these technologies represented a major step forward, OCR-based systems struggled with accuracy, required extensive preprocessing, and lacked the ability to interpret nuanced or contextual meaning.

Recent advancements in Large Language Models (LLMs) have redefined this landscape. Unlike traditional OCR systems, LLMs can directly process unstructured text, enabling semantic understanding, contextual reasoning, and relational mapping across multiple sources. This makes them particularly valuable in testimony analysis and case correlation, where identifying hidden inconsistencies, recurring patterns, and cross-case links is critical. Consequently, AI-driven testimony analysis and data correlation systems present an opportunity to enhance both efficiency and reliability in modern criminal investigations.

Rahman and Kaur [1] emphasized that traditional methods of testimony analysis are prone to fragmentation and inefficiency, highlighting the importance of automation in criminal investigations. Early solutions combined OCR for digitization with NLP for entity recognition, enabling conversion of physical reports into searchable formats. Singh et al. [2] demonstrated that NLP significantly reduces manual intervention by automatically categorizing and classifying textual data, thus supporting investigators in managing large datasets.

Baltrūnienė [3] highlighted AI's growing role in forensic and legal contexts, particularly in enhancing data accessibility and minimizing human bias. Similarly, Das et al. [5] explored AI-driven advancements in forensic investigations, showing their potential to accelerate investigative processes. However, despite these benefits, OCR-based pipelines remained constrained by preprocessing requirements and limited contextual understanding.

The emergence of LLMs addresses many of these limitations. Unlike OCR-dependent frameworks, LLMs are capable of extracting entities and interpreting semantic relationships directly from raw unstructured text. This enables real-time context-sensitive processing, relational mapping between testimonies, and integration with multiple databases. Despite these advancements, there is limited research on applying LLMs specifically to testimony analysis and case correlation in criminal investigations, making this an area with high potential for exploration.

1.2. Literature Review & Research Gap

Multimodal OCR and Document Understanding: Recent work shows that multimodal large language models (mLLMs) can dramatically improve text transcription and information extraction from images. Greif *et al.* [1] demonstrate that off-the-shelf mLLMs outperform state-of-the-art OCR on historical documents. Their best mLLM achieved substantially higher accuracy than conventional OCR and, after a novel LLM-based post-correction step, produced transcriptions with **<1% character error rate** without any image pre-processing or fine-tuning. Crucially, they also show mLLMs can extract named entities directly from the text-image input and output structured data [1]. These findings suggest that end-to-end multimodal models can subsume traditional OCR and parsing pipelines, using visual context to interpret layout and content in one step.

Building on this, Patel [2] highlights how GenAI-based OCR models leverage transformer attention to fuse visual and textual context. Unlike legacy OCR (which only analyzes pixel shapes and rigid templates), GenAI models analyze the relationships between text, images, and document structure [2]. For example, GenAI-assisted systems can interpret complex documents (e.g. scientific papers or forms) by jointly analyzing textual content *and* surrounding tables, charts or annotations [2]. This holistic vision–language understanding enables far more accurate extraction of structured information even from unstructured layouts. In practice, GenAI OCR excels at recognizing handwritten text and poor-quality scans: it can "infer" missing or illegible characters by reasoning about the surrounding context [2], and it applies image preprocessing (noise reduction, skew correction) internally to boost accuracy [2]. Overall, these advances mean that modern multimodal LLMs can serve as OCR-free engines: ingesting scanned pages (including handwriting) directly and yielding high-fidelity text and data, something traditional OCR pipelines struggle to match.

Generative AI vs. Traditional OCR: The shift from traditional OCR to generative AI brings several key advantages. Traditional OCR systems are rule-based and optimized for clean, well-formatted printed text, requiring manual configuration for each document style [2]. In contrast, GenAI-powered OCR uses deep neural nets and transformer architectures to *adapt* to diverse layouts and noisy data [2]. Patel emphasizes that GenAI models learn dynamically from data: they handle complex fonts, multi-column layouts, and degraded images without hand-crafted rules [2]. For instance, GenAI OCR can be prompted or fine-tuned with just a few examples of a new document type (few-shot learning) to generalize to unseen formats [2]. It also unifies the entire workflow: a single GenAI model can perform image cleanup, text

detection, and language understanding in one pass, rather than chaining multiple specialized tools [2]. These capabilities translate into higher accuracy and flexibility. As Patel notes, GenAI-assisted OCR "introduces contextual understanding, few-shot learning, and multimodal processing" that extract meaningful insights from even highly unstructured documents [2]. In sum, generative OCR is able to surpass traditional methods on tasks involving complex layouts, overlapped graphics, handwriting, or low-quality scans [2].

Multilingual Document Extraction: A critical open area is applying these LLM techniques in low-resource languages. Tamil and Sinhala, for example, have historically seen very limited NLP support. Ranathunga *et al.* [3] recently released a parallel English–Tamil–Sinhala corpus annotated for named entities, and used multilingual transformers (e.g. mBERT, XLM-R) to establish baseline NER performance [3]. They confirm that pretrained multilingual LMs can outperform older methods on Sinhala and Tamil NER, but they also stress that even these newer techniques have scarcely been applied to those languages [3]. Indeed, most multimodal LLM research remains English-centric: Yue *et al.* [4] note that models trained on Western data exhibit **"diminished performance in multilingual settings"** [4]. In practice, this means that end-to-end LLM pipelines rarely support non-Latin scripts like Sinhala or Tamil. For legal documents specifically, virtually no prior work tackles automated extraction from, say, police reports written in Sinhala or Tamil. Existing systems either ignore these languages or rely on separate OCR engines plus rule-based parsing, which lack the adaptive strengths of LLMs. Thus, the multilingual and cross-script dimension is a major gap in current literature.

Predictive Analytics and Legal Outcome Forecasting: Parallel to extraction tasks, LLMs have been explored for legal judgment prediction – forecasting case outcomes from textual facts. Recent studies show promise: integrating LLMs into Legal Judgment Prediction (LJP) reduces the need for manual feature engineering and boosts predictive accuracy [5]. For example, Kmainasi *et al.* [5] created an Arabic LJP dataset and found that fine-tuned open-source LLMs (like LLaMA) can match or exceed larger models in predicting judgments [5]. In criminal law, tailored BERT-based models have also outperformed classical methods in outcome prediction [5]. However, these successes are generally confined to high-resource languages and formal judgment texts. As noted, LLMs still "struggle with low-resource, non-Latin languages" without extensive localization [5]. Moreover, most LJP research begins with already-digital case descriptions or judgments, not raw investigative documents. There is little work on forecasting legal outcomes directly from unstructured inputs like scanned police reports or mixed-language court orders. In other words, existing predictive analytics in law do not usually integrate multimodal extraction or tackle Sinhala/Tamil texts.

Research Gaps and Novel Contributions: Taken together, the literature shows that multimodal LLMs and generative OCR are revolutionizing document understanding, and that LLMs can drive legal outcome predictions. Yet significant gaps remain: no prior system unifies these advances in a multilingual criminal justice context. To be explicit:

- **OCR-Free Multimodal Processing:** Traditional frameworks still treat OCR and downstream analysis separately. Our system leverages Google's Gemini 2.0 Flash – a multimodal LLM with a huge context window – to process scanned PDFs and even handwritten pages directly. This follows the vision of LLM-based OCR (Greif *et al.* [1]) but applies it in a legal setting. No existing work has used Gemini-2.0-like models to eliminate separate OCR for police reports or court orders.
- **Structured Field Extraction:** We extract 24 specific legal fields (e.g. victim details, evidence, charges) into structured JSON. Prior research shows that mLLMs *can* output structured data [1], but such end-to-end JSONification in legal workflows is new. Most studies focus on general NER categories; ours precisely targets judicial fields.
- **Multilingual Support:** Unlike most LLM studies, our pipeline natively handles English, Sinhala and Tamil. This addresses the dearth noted in the literature: while Ranathunga *et al.* [3] provide a resource for Sinhala/Tamil NER, there is no documented end-to-end system that processes Sinhala and Tamil legal documents. Our work fills this gap by incorporating multilingual OCR and understanding into a single framework, which to our knowledge is novel in the context of criminal justice.
- **Integrated Predictive Analytics:** Crucially, we link information extraction with real-time outcome forecasting. Existing legal NLP research typically separates the extraction of facts from the prediction of case outcomes. In contrast, our system automatically generates structured summaries **and** predicts probable legal outcomes from the same input. This combination of multimodal extraction with case-level prediction is not found in prior literature.

In summary, while advances in multimodal LLMs and generative OCR have been documented [1], [2], and legal NLP has progressed in isolation [5], no prior work offers a multilingual, end-to-end platform that processes raw investigative documents and generates both structured data and outcome predictions. The proposed system thus advances the state of the art by bridging these domains and addressing the under-served needs of criminal case processing.

1.3. Research Problem

The process of handling testimonies, police reports, and other investigative documents in traditional criminal investigations is often inefficient, fragmented, and vulnerable to human error. Manual data handling methods require investigators to review large volumes of unstructured documents, cross-reference testimonies, and search for patterns across cases. This process is time-consuming and highly dependent on the individual expertise of investigators, making it susceptible to bias, oversight, and inconsistencies. As a result, critical connections between cases may be overlooked, and the pace of investigations is slowed, delaying the delivery of justice.

Although the adoption of Artificial Intelligence (AI) has begun to address some of these issues, current systems remain limited in several respects. Early approaches employing Optical Character Recognition (OCR) and Natural Language Processing (NLP) have made it possible to digitize documents and extract structured insights, but these methods struggle with contextual inaccuracy, high preprocessing requirements, and limited scalability. OCR systems are not always reliable when faced with handwritten or noisy reports, while many NLP frameworks are narrowly focused on entity recognition without providing deeper semantic or relational analysis. Furthermore, existing solutions are often fragmented, operating as stand-alone tools without the ability to synchronize in real time with law enforcement databases or to integrate multiple data sources into a unified platform.

With the advancement of Large Language Models (LLMs), there is now significant potential to overcome these limitations. LLMs are capable of interpreting unstructured text with greater contextual understanding, enabling not only entity extraction but also semantic classification, relationship mapping, and inconsistency detection across testimonies and incidents. However, their application in criminal investigations has been limited, and current literature shows a lack of comprehensive systems that incorporate LLM-driven extraction into real-time, scalable, and investigator-friendly frameworks.

This creates a critical research problem. Investigators require a system that can automate the extraction and organization of data from diverse case documents while also providing reliable, real-time synchronization with secure databases. Such a system must minimize manual intervention, improve accuracy and efficiency, and present data through user-friendly dashboards that support quick, evidence-based decision-making.

1.4. Research Objectives

Main objectives

The primary objective of this research is to design and implement an advanced AI-powered OCR system for automated data collection and management within the context of criminal investigations. The system seeks to leverage the combined strengths of Large Language Models (LLMs) and Natural Language Processing (NLP) to extract, organize, and synchronize critical information police reports and store them in a secure database. By doing so, the solution aims to overcome the inefficiencies of manual data handling, which is often time-consuming, error-prone, and fragmented.

A central goal of the system is to automate the extraction of meaningful information from unstructured text, transforming raw case records into structured, searchable, and

contextually relevant formats. This structured data is then stored within a secure and scalable database, ensuring investigators have reliable access to both processed and original information. Additionally, the system incorporates a user-friendly interface that enables investigators to efficiently retrieve, filter, and analyze case data in real time. By minimizing the level of manual intervention required in data handling, the solution enhances both accuracy and efficiency, ultimately providing a unified framework that supports faster, more reliable, and evidence-based decision-making in modern criminal investigations.

Specific Objectives

The specific objectives of this research focus on the detailed tasks required to successfully implement the proposed AI-driven data collection and management system. These objectives provide the foundation for achieving the broader research goals while ensuring technical and functional effectiveness.

- Customizable AI-powered extraction algorithms capable of accurately digitizing police reports and other physical documents into reliable, searchable digital formats.
- Design and implement NLP models to extract structured insights from unstructured text, including critical entities such as names, locations, dates, and timelines.
- Develop mechanisms for real-time synchronization with a secure database to ensure investigators have immediate access to up-to-date, actionable information, with the ability to generate downloadable reports.
- Design a user interface (UI) with advanced filtering and search features to support investigators in retrieving, analyzing, and correlating critical case data with ease.
- Implement robust data preprocessing pipelines to clean, anonymize, and standardize data before analysis, ensuring compliance with privacy and legal requirements.
- Evaluate system performance through pilot testing using simulated case data, assessing accuracy, usability, scalability, and reliability under realistic investigative scenarios.

2. Methodology

2.1. Requirement Gathering

The requirement gathering and analysis phase formed the foundation of this research, ensuring that the system design was guided by the actual needs of investigators in Sri Lanka. This stage was critical in aligning the technological solution with the practical challenges faced by law enforcement personnel in handling testimonies, case reports, and databases. The process combined multiple approaches, including a literature survey, field visits, interviews, and data collection. These methods provided both theoretical insights and empirical evidence to identify the functional and non-functional requirements of the proposed system.

Literature Survey

The requirement-gathering process commenced with a comprehensive review of existing literature on the use of Artificial Intelligence (AI), Natural Language Processing (NLP), and Large Language Models (LLMs) in criminal investigations. Previous studies provided valuable insights into how technologies such as OCR, NLP, and machine learning have been applied to legal data analysis and evidence management in other jurisdictions. The survey revealed recurring issues such as inefficiencies in manual data handling, the limitations of OCR in processing handwritten or noisy reports.

This review helped to establish a baseline understanding of existing research gaps and guided the adaptation of modern AI-driven tools ,particularly LLMs ,to address the unique challenges within the Sri Lankan law enforcement context. It also informed the selection of technologies for the system's design, ensuring that the solution leveraged best practices from prior studies while remaining adaptable to local needs.

Field Visit

To validate the findings of the literature review and gather firsthand insights, field visits were conducted at four police stations in Sri Lanka. These visits were instrumental in understanding the day-to-day operations of investigators and the administrative processes associated with managing case data.

- Interviews with police officers to explore the practical difficulties encountered during investigations, such as the time required to manually review case files, challenges in cross-referencing testimonies, and issues in retrieving archived reports

- Observing real case reports and files to examine the structure, format, and language used in documentation. This provided direct exposure to the nature of unstructured data, highlighting the variations in style, terminology, and completeness of reports.
- Conducted further online interviews with police personnel to understand the different procedures followed and challenges faced during the investigation process.
- Sought frequent guidance from a retired Chief Inspector of police as our external supervisor to ensure our system design aligns with real investigative practices.

Data Collection

Following the field visits, anonymized police reports from past incidents were collected to create a dataset for experimentation and model training. These reports were carefully curated to ensure compliance with privacy and ethical standards, with all personally identifiable information removed. Additionally, sample police reports were created to simulate real investigative scenarios, ensuring that the system could be tested on both authentic and synthetic data.

The data collection process served multiple purposes. Firstly, it provided the training material for NLP and LLM-based modules responsible for entity recognition, semantic classification, and testimony correlation. Secondly, it enabled the development of preprocessing pipelines for cleaning, anonymizing, and standardizing data prior to analysis. Finally, the collected reports acted as test cases during the pilot evaluation phase, ensuring that the system's accuracy, scalability, and usability were assessed against real-world scenarios.

1.1. Feasibility Study

A feasibility study was conducted to assess the practicality of developing and deploying the proposed AI-driven system for testimony analysis and case correlation in criminal investigations. This evaluation was critical to ensure that the system could be successfully designed, implemented, and integrated within the operational and legal framework of law enforcement in Sri Lanka. The study examined four major dimensions: technical feasibility, operational feasibility, economic feasibility, and legal/ethical feasibility.

Technical Feasibility

The technical feasibility of the project was evaluated by analyzing the suitability of selected technologies, tools, and frameworks for system implementation. Python, with its extensive machine learning ecosystem, provides the backbone for AI and NLP tasks, while frameworks such as spaCy, NLTK, and Pandas support entity recognition, text preprocessing, and data manipulation. Large Language Models (LLMs), such as Gemini 2.0, enhance semantic understanding and contextual extraction, offering superior performance compared to traditional OCR-based pipelines.

The frontend of the system is supported by Next.js, which ensures responsive, real-time access to data, while MongoDB provides a scalable and secure storage mechanism for structured and unstructured case information. Cloud-based infrastructure, particularly Google Cloud Console and APIs, ensures reliability, high availability, and robust security, making the system adaptable to both local and large-scale deployments.

Given the availability of these mature technologies, the system is deemed technically feasible. The modular architecture also allows for future enhancements, such as integrating speech-to-text features or extending functionality for mobile-based data entry through Google ML Kit.

Operational Feasibility

Operational feasibility focuses on the system's practicality in real-world investigative workflows. Field visits to Sri Lankan police stations revealed that investigators often face challenges in managing unstructured reports, manually cross-referencing testimonies, and retrieving archived data. The proposed system addresses these challenges by automating data extraction, synchronizing reports in real time, and providing a user-friendly dashboard for search and filtering.

The interface, built with Tailwind CSS and Next.js, ensures that even users with limited technical expertise can interact with the system effectively. Pilot testing with anonymized police reports and simulated case data demonstrated that investigators could significantly reduce the time required to identify inconsistencies and cross-case correlations.

Therefore, from an operational standpoint, the system is not only viable but also poised to significantly improve investigative efficiency and decision-making.

Economic Feasibility

Economic feasibility was assessed by evaluating the cost of development, deployment, and long-term maintenance. The project leverages open-source tools such as Python, PyCharm, VS Code, NLTK, and spaCy, which minimize software licensing costs. Cloud-based services, including Google Colab and Google Cloud APIs, offer cost-effective access to computational resources, eliminating the need for heavy local infrastructure.

The main expenses are associated with hosting services, integration costs, Gemini 2.0 (only when scaling up the system) and potential training sessions for investigators. Based on initial estimates, the system can be deployed with a relatively modest budget compared to traditional enterprise solutions. Furthermore, the long-term benefits ,such as reduced case resolution time, improved accuracy, and fewer errors in testimony analysis ,justify the initial investment by delivering substantial operational savings.

Thus, the system is economically feasible, with costs aligned to achievable budgets for pilot-scale adoption within law enforcement agencies.

Legal and Ethical Feasibility

Given that the system deals with sensitive criminal investigation data, compliance with legal and ethical standards is essential. The data collection process involved anonymization of police reports to ensure that no personally identifiable information was disclosed during development and testing. Security measures, including encryption and secure database management, were incorporated to maintain confidentiality and integrity of data.

Additionally, ethical considerations such as minimizing algorithmic bias and ensuring transparency in AI-driven outputs were prioritized. LLMs were customized to limit hallucinations and irrelevant responses, ensuring that the system provides investigators with reliable, explainable results. In alignment with Sri Lanka’s data protection regulations and international best practices, the system design ensures adherence to privacy and security protocols.

Hence, the project is legally and ethically feasible, with safeguards in place to protect sensitive data and maintain public trust.

Overall Feasibility

The feasibility study confirms that the proposed system is practical and viable across all evaluated dimensions. Technologically, it leverages proven frameworks and state-of-the-art LLMs. Operationally, it directly addresses pain points identified during field visits and interviews with investigators. Economically, it minimizes costs through open-source and cloud-based solutions while promising significant long-term benefits. Finally, legal and ethical safeguards ensure that sensitive investigative data is protected and responsibly managed.

2.2. System Design

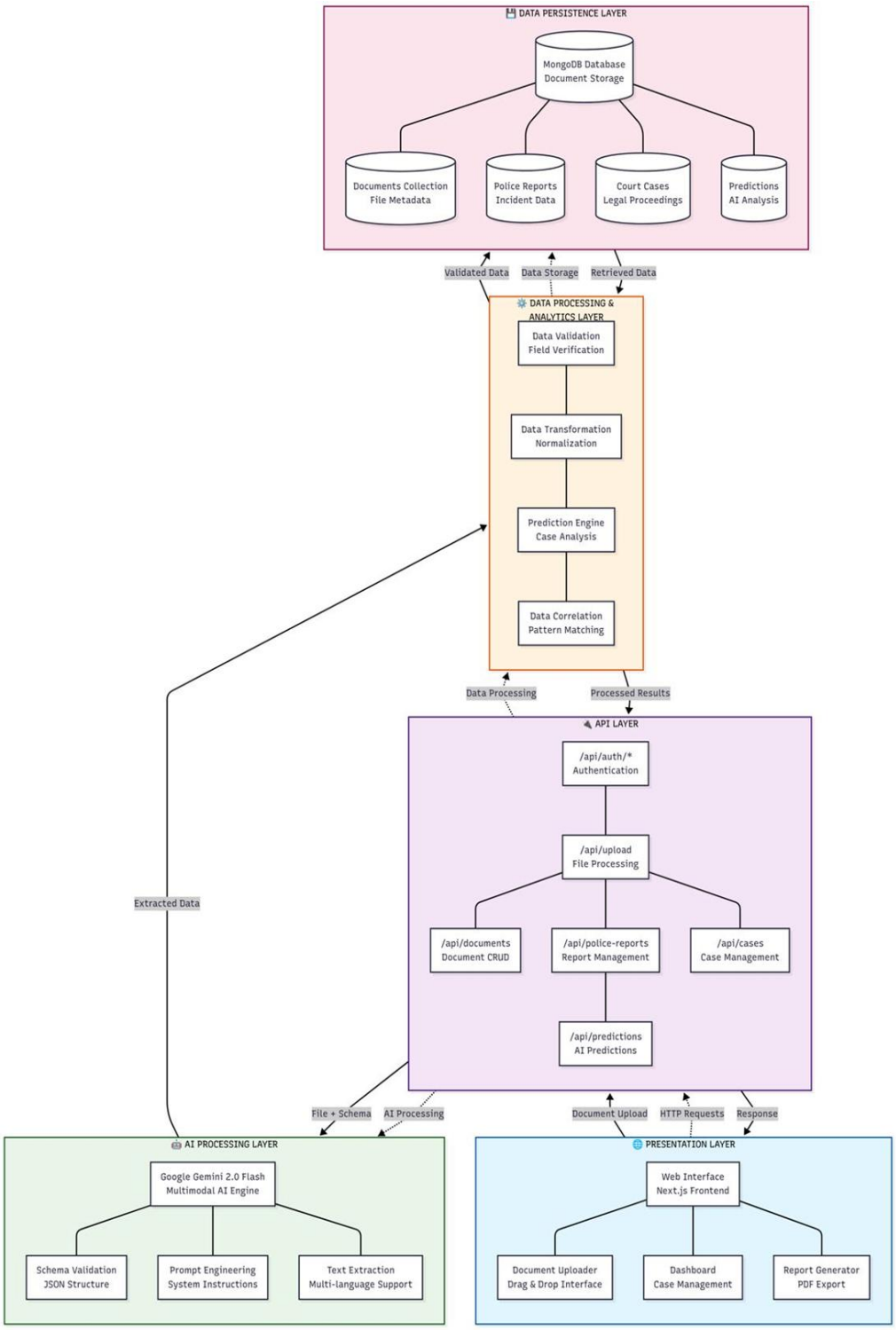


Figure 1 : System Design

The component architecture for extracting data from police reports and court orders using AI-powered OCR with Gemini LLM follows a layered, modular design that ensures scalability, maintainability, and high accuracy in document processing. The system is built on a multi-tiered architecture that separates concerns and enables efficient processing of legal documents.

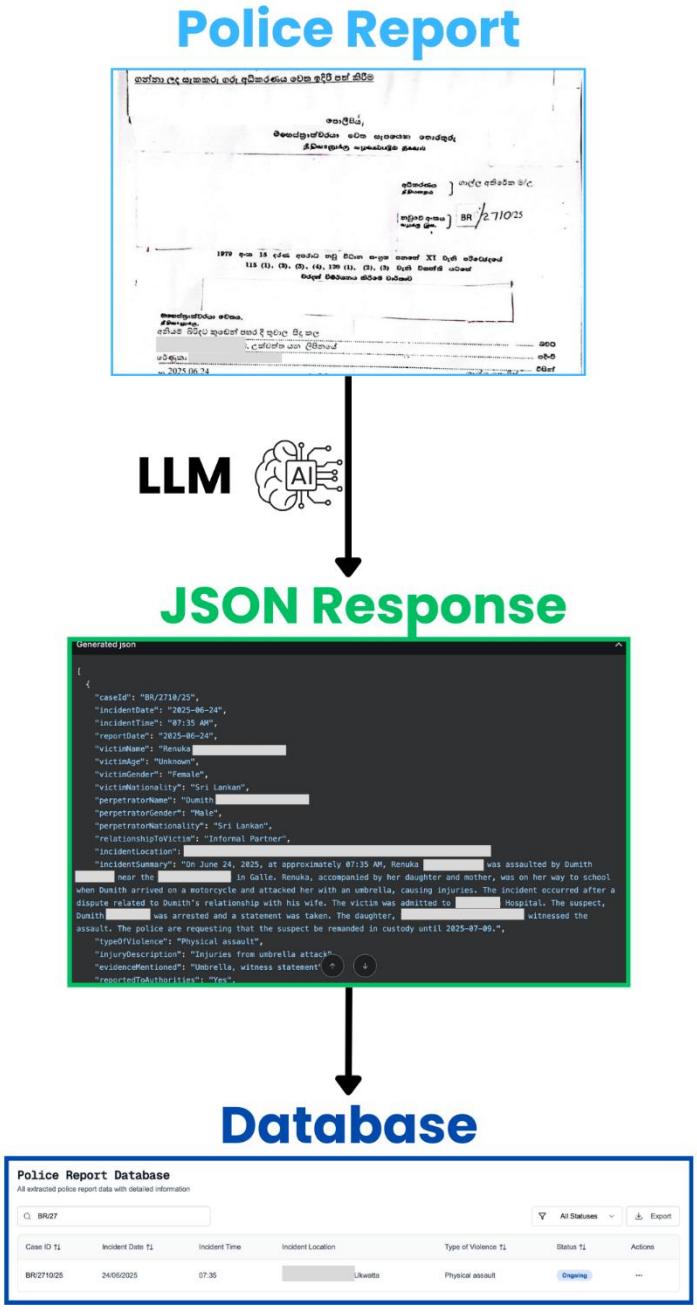


Figure 2 : Data Extraction

1. Input Layer

The Input Layer constitutes the primary interface for data acquisition and user engagement. This layer supports flexible ingestion methods, enabling the system to accommodate heterogeneous document formats and sources:

```
const policeReportSystemInstruction =
"You are an expert in extracting structured data from unstructured or semi-structured text in police reports. Given a file (which may be an image, PDF, DOCX, CSV,
"caseId (e.g., 'WCIB 367/04', 'BR 1082/25')\n" +
"incidentDate (e.g., 'February 27, 2025')\n" +
"incidentTime (e.g., '10:30 AM', '14:45', or 'Unknown')\n" +
"reportDate (e.g., 'March 1, 2025')\n" +
"victimName (e.g., 'Alina Oslopova' or leave 'Unknown' if redacted)\n" +
"victimAge (e.g., '25 years', or 'Unknown')\n" +
"victimGender (e.g., 'Female', 'Male', 'Unknown')\n" +
"victimNationality (e.g., 'Sri Lankan', 'Russian', or 'Unknown')\n" +
"perpetratorName (e.g., include if mentioned; else 'Unknown')\n" +
"perpetratorGender (e.g., 'Female', 'Male', 'Unknown')\n" +
"perpetratorNationality (e.g., 'Sri Lankan', 'Russian', or 'Unknown')\n" +
"relationshipToVictim (e.g., 'Spouse', 'Stranger', 'Friend', 'Employer', 'Unknown')\n" +
"incidentLocation (e.g., 'No. 39/3C, Kaluwella, Galle')\n" +
"incidentSummary (a detailed summary of the incident, including key events and context)\n" +
"typeOfViolence (e.g., 'Physical assault', 'Verbal threat', 'Sexual harassment', 'Unknown')\n" +
"injuryDescription (if any: e.g., 'swollen cheek', 'bleeding nose')\n" +
"evidenceMentioned (e.g., 'Medical Report', 'CCTV footage', 'Police Scene Report')\n" +
"reportedToAuthorities ('Yes', 'No')\n" +
"actionTaken (e.g., 'Victim taken to hospital', 'CCTV retrieved', 'Suspect summoned')\n" +
"recurrence (e.g., 'First-time incident', 'Repeat incident', 'Ongoing domestic violence')\n" +
"caseStatus (e.g., 'Ongoing', 'Referred to court', 'Concluded', 'Unknown')\n" +
"relevantLaws (e.g., 'Sri Lanka Penal Code 314, 316', or 'Children's Charter 1989')\n" +
"priorCriminalHistory (e.g., 'No prior record', 'Convicted of theft in 2020', or 'Unknown')\n" +
"The text may not follow a consistent format, and some fields may be missing, ambiguous, or in a non-English language (e.g., Sinhala).\n\n" +
"Guidelines:\n" +
"1. For caseId, look for identifiers like 'WCIB', 'MCR/', 'BR', or similar (e.g., 'WCIB 367/04', 'MCR/122/25'); if unclear, use 'Unknown'.\n" +
"2. For incidentDate and reportDate, accept various formats (e.g., 'February 27, 2025', '2025-02-27') and distinguish between them. Translate Sinhala dates to Eng
"3. For victimName, extract as provided (e.g., 'Alina Oslopova', '@@ෙ'); if redacted or unclear, use 'Unknown'.\n" +
"4. For ages, extract numerical values or phrases like '25 years'; if not specified, use 'Unknown'.\n" +
"5. For gender, identify terms like 'Male', 'Female', or Sinhala equivalents (e.g., '@ෙ@' for 'Male'); if unclear, use 'Unknown'.\n" +
"6. For victimNationality and perpetratorNationality, infer from context (e.g., 'Sri Lankan' from location or name); if unclear, use 'Unknown'.\n" +
"7. For relationshipToVictim, infer from context (e.g., 'Spouse' in domestic cases, 'Stranger' in theft); translate if in Sinhala; if unclear, use 'Unknown'.\n" +
```

Figure 3 : Prompt for data extraction

- **Document Upload Interface:** A Next.js-based web application forms the user-facing front end, featuring a drag-and-drop mechanism that supports diverse file types such as PDFs, Word documents (DOCX), scanned images (JPG, PNG), CSV, and plain text (TXT) files. The interface integrates real-time file validation, upload progress monitoring, and document categorization capabilities (distinguishing police reports from court orders), optimizing usability and accuracy in document submission.
- **Multi-Channel Data Acquisition:** Document ingestion occurs via direct web uploads and secure API endpoints, facilitating seamless integration with external law enforcement databases and legacy systems. This dual-path acceptance caters both to digitized versions of case files and scanned hardcopies, ensuring comprehensive data coverage.
- **Security and Access Control:** Role-based authentication and authorization mechanisms are enforced through Next.js middleware, restricting document access and upload privileges to authorized personnel only. This layer ensures compliance with regulatory and privacy standards by safeguarding sensitive investigative data against unauthorized exposure.

2. Document Processing Layer

At the core of the system lies an advanced Document Processing Layer that harnesses Google Gemini 2.0 Flash's multimodal AI capabilities to perform intelligent document comprehension without relying on traditional OCR pipelines, thereby overcoming limitations of accuracy and preprocessing overhead:

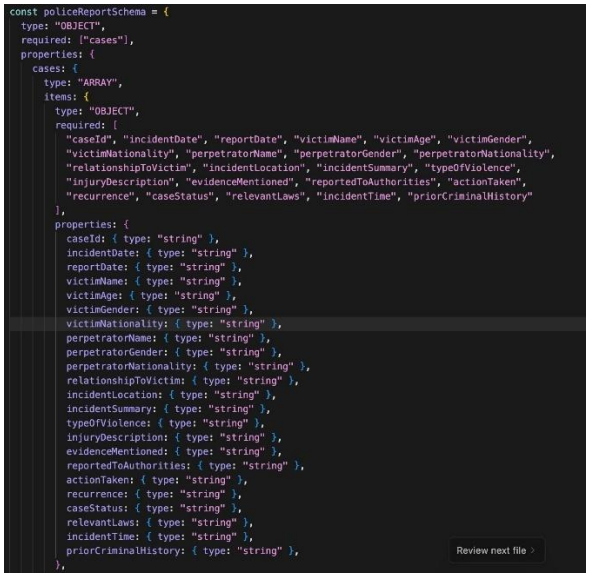


Figure 4 : Police report Data schema

- **Multi-Modal Document Processing:** This layer processes raw document inputs ,including images, scanned PDFs, and text files, by simultaneously performing text extraction, layout and structural analysis, handwritten text recognition, and multilingual interpretation (e.g., Sinhala to English translation). Additionally, it accurately extracts tabular and form-based data embedded within forensic documents.
- **Document Type Classification:** Leveraging content-based semantic cues, the system automatically categorizes documents into police reports and court orders, directing them through domain-specific analysis pipelines tailored to the unique structural and informational characteristics of each document type.
- **Real-Time Processing Pipeline:** Immediate document transformation is achieved through a streamlined pipeline that converts input files into Base64-encoded representations suitable for Gemini API processing. Extracted data is returned as structured JSON schema outputs, accompanied by metadata such as processing duration and system performance metrics.

3. AI Processing Layer

The AI Processing Layer is responsible for intelligent data extraction and contextual analysis utilizing sophisticated prompt engineering in conjunction with Google Gemini 2.0 Flash:

- **Model Configuration:** The Gemini model is finely tuned with domain-specific parameters (e.g., temperature of 0.5, topP of 1, topK of 1) to balance precision and diversity during text generation, optimizing for forensic accuracy and consistency.
- **System Instructions Engine:** A library of specialized prompts equips the AI to differentiate between document contexts, apply privacy-preserving transformations (e.g., anonymizing personal identifiable information), support multilingual inputs, and extract contextually relevant fields even when explicit data is missing.
- **Structured Output Schema:** Extraction results adhere to predefined JSON schemas that enforce uniformity, comprising over 24 fields for police reports (inclusive of case details, victim and perpetrator profiles, incident narratives) and 15 fields for court orders (capturing legal procedures, charges, verdicts, and sentencing information). This structured approach enables high fidelity in data representation and downstream processing.

4. Data Processing and Storage Layer

Following extraction, the system incorporates a robust Data Processing and Storage Layer to validate, normalize, and persist case information securely:

- **Data Transformation and Validation:** Extracted JSON data undergoes comprehensive parsing to ensure schema conformity, correct erroneous or incomplete values, execute cross-field consistency verifications, and introduce placeholder values (“Unknown”) where data is legitimately missing, maintaining data integrity.
- **Database Operations:** Utilizing MongoDB coupled with Mongoose ODM, the system stores documents and their associated structured data as linked entities. Unique document identifiers (UUIDs) support traceability, while audit logs capture processing events and timing metrics to facilitate system monitoring and forensic auditing.
- **Data Persistence Strategy:** The repository maintains document metadata (file attributes, processing timestamps), structured case data, and version-controlled updates to support case lifecycle management and historical record preservation.

5. Intelligence and Analytics Layer

This advanced layer applies AI-driven analytics to enhance investigative decision-making and uncover latent case insights:

- **Predictive Analytics Integration:** Employing machine learning models on extracted data, the system forecasts case outcomes, assesses risk profiles, and evaluates probability metrics. Additionally, it identifies recurrent patterns and behavioral trends, thereby augmenting investigative heuristics.
- **Data Correlation Engine:** Sophisticated algorithms analyze temporal relationships across cases, map geographic proximities, detect recurring offenders or modus operandi, and establish cross-case linkages to guide comprehensive investigations.

6. Output and Presentation Layer

Finally, the system offers versatile interfaces and reporting capabilities tailored for investigative stakeholders:

- **User Dashboard Interface:** A responsive web dashboard supports real-time case monitoring, enriched by advanced search, filtering mechanisms, and document viewers that overlay extracted data for inline validation. Interactive visualizations relay case status, analytics, and pattern insights intuitively.
- **Report Generation System:** Employing js PDF and react-to-print libraries, the system generates customizable PDF reports aligned with organizational templates and user roles. These reports can be exported and integrated with external judicial or administrative systems to facilitate case documentation and presentation.
- **API Services Layer:** RESTful APIs provide controlled data access, enable real-time synchronization between subsystems, and manage authentication tokens for secure external integration, ensuring interoperability within broader law enforcement infrastructures.
- **System Security and Technical Considerations**

  End-to-end security underpins the architecture through rigorous API key management, input sanitization, rate limiting, secure file handling, and temporary storage strategies to prevent data leakage or denial-of-service vulnerabilities. The processing pipeline supports batch uploads, real-time progress tracking, automatic error recovery, and retry mechanisms to ensure operational resilience and scalability across diverse investigative workloads.

2.3. Implementation

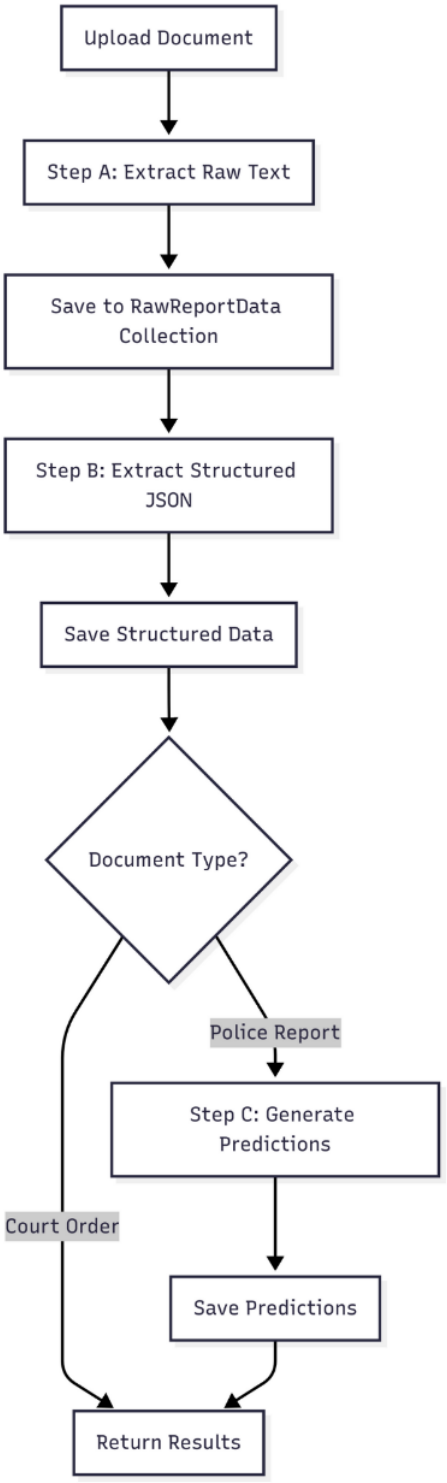


Figure 5 : Flow chart of Chain prompt

The implementation of the proposed system was carried out in several phases to ensure that both functional and non-functional requirements were met. The system provides a secure environment for investigators to register, manage case data, and analyze information extracted from police reports and related documents.

- **User Registration and Access Control**

  User registration begins with the creation of an account within the system. To safeguard against unauthorized access, each registration request undergoes verification by an administrative officer, who validates the identity of the applicant before granting access. This process ensures that only legitimate law enforcement personnel are able to utilize the system, thereby reducing the risk of external parties gaining entry.

- **People Registry Database**

  During an investigation, details of the involved parties are stored in a dedicated People Registry Database. Information recorded includes the individual's full name, date of birth, gender, national identity card number, address, and a photographic record. This structured repository provides investigators with a centralized source of personal data relevant to ongoing and historical cases, ensuring consistency and accessibility throughout the investigation process.

- **Investigator Dashboard**

  Upon successful login, users are presented with the Home Dashboard, which serves as the central hub of the application. This interface allows investigators to view Recent Investigations and Active Investigations, along with corresponding progress levels and due dates. The Investigations Page provides access to both ongoing and archived cases, while the Learn Page delivers global crime updates and interactive tutorials designed to enhance investigators' knowledge and awareness of international practices.

- **Document Upload and Data Extraction**

  The system enables investigators to upload documents by referencing a unique Report ID. Users are prompted to specify the type of document being uploaded, such as a Police Report or a Court Order. Once confirmed, the system automatically processes the file, extracting relevant data and converting it from unstructured text into structured formats.

  The extracted data is organized within the Report Details section. This is further divided into categories:

1. **Report Information**: Case ID, incident date and time, report date, case status, recurrence, and relevant legal provisions.
2. **Actions and Authorities**: Actions taken, reporting details to relevant authorities, and the associated Document ID.
3. **Incident Evidence**: Divided into *Incident Details* (location, type of violence, and summary) and *Injuries and Evidence* (injury descriptions and references to material evidence).
4. **Involved Parties**: Records the name, age, gender, nationality, relationship to victim, and any prior criminal history of victims and perpetrators.
5. **Documents**: Provides a preview of the original physical report, alongside the ability for users to make manual edits if necessary.

The system further allows investigators to generate and download structured reports in a printable PDF format. Case Summaries, including AI-generated insights and predictions derived from extracted data, are also available within this section.

- **Report Management and Analytics**

  Processed police reports can be revisited through the Recent Documents tab, while the Processing Stats module offers a statistical overview of system performance. This includes data on average processing times and the total number of documents processed across daily, monthly, and yearly periods. Such analytics enable investigators and administrators to monitor system usage and efficiency.

- **Case Creation and Management**

  A new investigation can be created within the system by recording key metadata such as the case title, case type, priority level, involved parties, and any associated reports. This functionality ensures that case files remain structured, easily accessible, and dynamically linked to the documents and data stored within the system.

2.4. Technologies Used

The development of the proposed AI-driven automated data collection and management system required a combination of programming languages, frameworks, cloud services, databases, and supporting libraries. Each technology was carefully selected based on its suitability for handling unstructured data, enabling real-time synchronization, and ensuring scalability, security, and usability in the context of law enforcement investigations. The following subsections describe the technologies used and justify their relevance to the system.

- **Python**

  Python was chosen as the core programming language for customizing the AI and data processing environment. It has an extensive ecosystem of libraries such as *NLTK*, *spaCy*, *Pandas*, and *OpenCV* that makes it particularly effective for Natural Language Processing, data manipulation, and computer vision tasks. Python's simplicity and readability also facilitate rapid prototyping and integration with AI frameworks.

  Justification: Python is the industry-standard language for machine learning and AI-driven projects, ensuring efficiency in development, high community support, and compatibility with research-based frameworks.

- **Next.js**

  Next.js was used to develop the web application that provides investigators with a responsive and scalable user interface. Built on React, Next.js supports server-side rendering, routing, and API integration, making it well-suited for real-time investigative dashboards.
  Justification: Next.js enhances user experience by offering optimized performance, modular design, and seamless integration with backend APIs, ensuring investigators can interact with case data quickly and efficiently.

- **Google Cloud Console (APIs)**

  Google Cloud Console provides cloud infrastructure and APIs necessary for authentication, storage, and hosting AI-powered services. Through this platform, APIs such as Google Cloud Vision and Google Generative AI SDK were managed and deployed.

  Justification: Using Google Cloud ensures reliability, scalability, and robust security, which are essential when handling sensitive law enforcement data.

- **MongoDB**

  MongoDB, a NoSQL database, was selected to store structured and unstructured case data. Its document-based architecture allows flexible storage of diverse data types, including police reports, extracted entities, and case correlations.

  Justification: MongoDB's scalability and flexibility make it an ideal choice for managing large volumes of heterogeneous investigation data while supporting real-time queries and analytics.

- **Gemini 2.0**

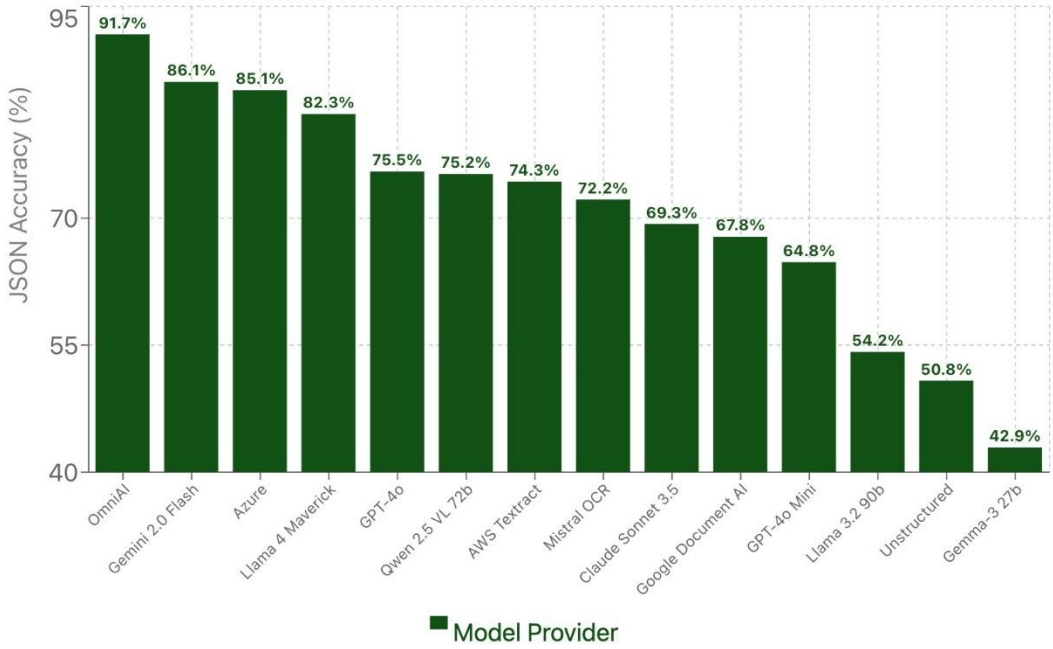


Figure 6 : Why choose Gemini and ChatGPT

Gemini 2.0, Google's advanced multimodal AI model, was employed for intelligent data extraction and question generation. It enables context-aware interpretation of unstructured text, enhancing the accuracy of entity recognition and testimony analysis.
Justification: Google's Gemini 2.0 Flash was selected for OCR implementation due to several key advantages:

Multimodal Capabilities: Unlike traditional OCR engines, Gemini can process various document formats (PDF, images, scanned documents) without requiring format-specific preprocessing.

Contextual Understanding: LLMs excel at understanding document structure and context, enabling better extraction of semi-structured data from legal documents.

Language Flexibility: Native support for multilingual text, crucial for Sri Lankan legal documents containing Sinhala, Tamil, and English text.

Structured Output: JSON schema enforcement ensures consistent, parseable output for downstream processing.

API Maturity: Google's Vertex AI provides reliable, enterprise-grade API infrastructure with comprehensive documentation and support.

- **Google Generative AI SDK**

  The Google Generative AI SDK was used to customize model interactions and integrate AI-driven capabilities into the application. This toolkit provides developers with access to generative AI features through structured APIs.
  Justification: By using the SDK, the system can tailor LLM outputs for specific investigative needs, ensuring outputs remain relevant, controlled, and explainable.

- **Google ML Kit**

  Google ML Kit was incorporated for mobile-friendly machine learning tasks, particularly when extending the system for mobile data entry or real-time evidence processing through device cameras.
  Justification: ML Kit enables lightweight, on-device intelligence, providing investigators with portable and offline AI capabilities without compromising security.

- **Tailwind CSS**

  Tailwind CSS was adopted for styling the user interface. Its utility-first framework allows rapid creation of clean, modern, and responsive layouts for the investigator dashboard.
  Justification: Tailwind reduces development time, ensures consistency across UI components, and provides scalability for future interface enhancements.

Integrated Development Environments (IDEs)

- **Visual Studio Code:** Used for web applications and API development due to its lightweight nature and wide ecosystem of extensions.
- **PyCharm:** Preferred for Python-based machine learning modules because of its advanced debugging, code inspection, and AI integration support.
  Justification: Using both IDEs optimized productivity, with VS Code enhancing frontend development efficiency and PyCharm providing robust Python support.

Libraries and Tools

- **Google Cloud Vision API:** Used for text recognition tasks, particularly when handling scanned documents or image-based evidence.
  Justification: Ensures accurate digitization and complements LLMs by preprocessing visual text data.
- **spaCy:** Applied for NLP-based entity recognition, including identification of people, locations, and dates within reports.
  Justification: SpaCy offers high accuracy and efficient processing, making it suitable for real-time investigation tasks.
- **NLTK (Natural Language Toolkit):** Utilized for text preprocessing tasks such as tokenization, stop-word removal, and stemming.
  Justification: NLTK provides a broad foundation for text cleaning, ensuring that extracted data is standardized before analysis.
- **Pandas:** Used for data manipulation and transformation, allowing structured representation of case data for visualization and reporting.
  Justification: Pandas simplifies handling of large datasets and supports integration with visualization modules.
- **OpenCV:** Applied for document image processing, including noise reduction and preprocessing of scanned reports.
  Justification: Enhances OCR and AI extraction accuracy by ensuring cleaner and more consistent inputs.

2.5. Functional and Non-Functional Requirements

Functional Requirements

The implemented system successfully met the functional requirements identified during the design stage. These functions were developed to address the core challenges faced by investigators in handling large volumes of unstructured data.

1. **Data Extraction from Police Reports and Witness Statements**
   The system was designed to extract information from police reports and witness statements using AI-powered data extraction. The final implementation integrated Large Language Models (LLMs) alongside preprocessing pipelines, significantly improving the accuracy of data capture from both typed and scanned documents. This enabled seamless digitization and ensured that investigators could work with standardized digital records rather than manually reviewing physical files.

2. **Entity Recognition through NLP**
   The system employed Natural Language Processing (NLP) models, including spaCy and transformer-based embeddings, to identify and extract key entities such as names, dates, locations, and events. This functionality allowed investigators to quickly isolate critical information within case files and reduced dependency on time-intensive manual reading of reports.

3. **Categorization and Organization of Data**
   Extracted information was categorized and stored in structured formats, including case summaries, incident timelines, and categorized evidence fields. Reports were automatically organized into predefined categories such as *Incident Details, Involved Parties, Evidence, and Legal References*. This ensured that investigators could navigate complex datasets with ease.

4. **Real-Time Synchronization with Secure Database**
   All extracted and structured data were synchronized with a MongoDB-based secure database in real time. This synchronization ensured that data entered into the system was immediately available for search, filtering, and cross-case referencing across multiple investigations.

5. **Search and Filtering Capabilities**
   The implemented system allowed investigators to perform searches by categories, keywords, and date ranges. Advanced filters were incorporated within the dashboard to support retrieval of reports by case ID, investigation status, or type of incident, enabling efficient navigation across large datasets.

6. **Secure Data Storage and Retrieval**
   Pre-processed and structured data were stored securely in a centralized database, allowing for both short-term accessibility and long-term archiving. Data retrieval was supported through dashboard modules that displayed structured case details, including metadata, evidence logs, and investigator notes.

Non-Functional Requirements

Beyond the core functionality, the system was designed to adhere to critical non-functional requirements to ensure reliability, usability, and compliance with security standards.

1. **Response Time and Performance**
   Document uploads and data extraction were optimized to generate structured data within a maximum response time of **five seconds** under standard testing conditions. This was achieved by leveraging cloud-based computational resources and efficient preprocessing pipelines, ensuring investigators could receive results in near real time.

2. **Scalability**
   The system architecture was designed to scale horizontally, enabling it to handle large volumes of reports and testimonies without performance degradation. The use of MongoDB, along with efficient indexing strategies, allowed for scalability in data storage and retrieval. This ensured that the system could be expanded to support investigations across multiple jurisdictions if required.

3. **User-Friendly Interface**
   A Next.js and Tailwind CSS-based dashboard was developed to provide an intuitive and visually clear interface. Investigators could navigate easily through case summaries, reports, and analytics without requiring prior technical expertise. Features such as drag-and-drop uploads, advanced filters, and real-time data visualization enhanced usability and investigator efficiency.

4. **Data Security and Privacy Compliance**
   Given the sensitivity of investigative data, strict security measures were implemented. All data in transit and at rest were encrypted, and user access was controlled through role-based authentication and administrator verification. The system was designed to comply with privacy standards, ensuring anonymization of sensitive information where necessary.

5. **System Availability and Reliability**

The system was deployed with a high availability configuration, ensuring uninterrupted access. Regular backups and fault tolerance mechanisms were incorporated to protect against data loss or downtime, supporting continuous use in high-stakes investigative scenarios.

6. **Multilingual Support**
   Recognizing the linguistic diversity of Sri Lanka, the system was implemented with multilingual processing capabilities. LLM-based text extraction and NLP pipelines were customized to handle reports in English, Sinhala, and Tamil, thereby improving accessibility for investigators across different regions.

User Requirements

The system was designed and implemented with the needs of investigators as the primary focus. During requirement gathering, user expectations were collected through field visits, interviews, and analysis of existing investigative workflows. These requirements were then translated into features that were implemented and tested to ensure usability, reliability, and efficiency in real-world scenarios.

1. **Document Upload for Automated Data Extraction**
   Investigators were able to upload police reports, witness statements, and other case-related documents directly into the system. This functionality was implemented through a secure file upload mechanism, where users specified the document type (e.g., *Police Report* or *Court Order*) before submission. Once uploaded, the system automatically processed the document using AI-driven extraction pipelines, converting unstructured data into structured formats such as case summaries, evidence logs, and timelines. This feature reduced the time and effort traditionally required for manual data entry.

2. **Dashboard for Search, Filtering, and Visualization**
   A central dashboard was developed to provide investigators with an intuitive interface for managing case data. The dashboard allowed advanced search and filtering by **case ID, keywords, categories, or dates**. Visual analytics such as **processing statistics, case timelines, and trends** were also included, enabling investigators to interpret large datasets quickly. This interactive environment allowed for efficient case navigation and improved situational awareness.

3. **Real-Time Retrieval and Review of Case Information**
   All uploaded and processed data were synchronized in real time with the system's secure database. Investigators could immediately retrieve and review updated case information without delay. This ensured that active investigations always reflected the latest data, reducing inconsistencies and enabling collaborative work between officers across different departments.

4. **Downloadable Structured Reports**
   Investigators were given the ability to generate and download structured case reports in **printable PDF format**. These reports contained key extracted information, including case metadata, evidence summaries, involved parties, and legal references. The feature ensured that investigators could maintain physical records when required by judicial processes while preserving the efficiency of digital workflows.

2.6. Domain Specific Considerations

1. Security Considerations

Given the sensitive nature of criminal investigation data, robust security measures are paramount to protect the confidentiality, integrity, and availability of information managed by the AI-assisted investigative system.

- Data Confidentiality and Privacy: Police reports, court orders, witness statements, and behavioral data (facial expressions, physiological signals) contain highly sensitive personal information. The system must comply with data protection regulations such as GDPR, HIPAA (where applicable), and local privacy laws. End-to-end encryption should be enforced for data at rest and in transit. Role-based access controls (RBAC) and multi-factor authentication (MFA) should restrict access to authorized personnel only.
- Secure Storage and Transmission: Structured and unstructured data must be stored in secure environments with robust database encryption and stringent backup protocols to prevent unauthorized access and data loss. Data transmitted across networks must use secure communication protocols like TLS/SSL to prevent interception or tampering.
- Audit and Traceability: All interactions with the system ,whether data uploads, queries, manual edits, or interrogation session activities ,should be logged with timestamps and user identification to provide an immutable audit trail. This helps investigate potential security breaches, ensures accountability, and supports legal admissibility of processed data.
- System Integrity and Availability: The solution must be resilient to cyberattacks including ransomware, denial-of-service (DoS), and insider threats. Implementations should include real-time monitoring, threat detection, and automated incident response mechanisms. High availability architectures (e.g., failover systems, load balancing) will minimize downtime, critical in time-sensitive criminal investigations.

- Secure AI Model Usage: AI components, including Large Language Models (LLMs), should be regularly validated to prevent adversarial attacks (e.g., data poisoning, model extraction attempts) that could compromise output reliability. Secure APIs and sandboxing techniques will maintain model integrity and prevent unauthorized model manipulation.

2. Social Considerations

The adoption of AI-driven tools in criminal justice must acknowledge broader societal impacts and ensure these technologies support equitable, trustworthy, and transparent practices.

- User Engagement and Training: Investigators and law enforcement personnel need comprehensive training to effectively utilize the system. Proper understanding of AI outputs, their limitations, and interpretation prevents overreliance on automated results and supports informed decision-making.
- Digital Divide and Accessibility: The system should be designed with usability in mind to accommodate users with varying digital literacy levels and different accessibility needs (e.g., multilingual support, WCAG compliance). This ensures equitable access across diverse law enforcement communities.
- Community Trust and Transparency: Transparency initiatives to communicate how AI assists investigations can improve public trust, especially by clarifying that AI provides decision support rather than decision making. Community engagement programs should educate stakeholders on benefits and limitations to manage expectations.
- Bias and Fairness: Proactively identifying and mitigating biases in training datasets and models is crucial to prevent reinforcing systemic inequalities in law enforcement outcomes. Diverse datasets, regular bias audits, and fairness-aware model training techniques help ensure equitable treatment of all demographic groups.
- Impact on Employment: Introducing AI automation may affect roles within investigative teams. Institutions should consider re-skilling efforts and collaborative AI workflows that enhance rather than replace human expertise, fostering acceptance and smoother transitions.

3. Ethical Considerations

Ethical principles must underlie the design and deployment of AI in criminal investigations to safeguard human rights, justice, and societal values.

- Respect for Privacy and Consent: Use of physiological signals, facial analysis, and voice recognition involves personal biometric data. Consent policies must be clearly defined, and data usage strictly limited to authorized investigative purposes to avoid unlawful surveillance or privacy violations.
- Accountability and Explainability: The system must provide transparent explanations for AI-driven outputs (e.g., why a suspect's response is flagged, how pattern detection was derived). Explainability fosters accountability and supports judicial fairness by enabling scrutiny of automated evidence and recommendations.
- Avoidance of Automation Bias: Investigators should retain ultimate responsibility for decisions. The system's role is advisory, and ethical safeguards must prevent blind trust in AI outputs that could lead to wrongful accusations or miscarriages of justice.
- Mitigating Harm and Protecting Rights: The system must be designed to prevent harm through errors or misuse. This includes mechanisms to contest AI-derived outcomes, human oversight in sensitive decisions, and safeguards against disproportionate surveillance or profiling.
- Addressing Ethical Use of Surveillance Technologies: Emotional and behavioral analysis during interrogations raises concerns about manipulation, coercion, and emotional privacy. Clear ethical guidelines and oversight must govern the deployment of such technologies to respect the dignity and rights of all individuals involved.
- Compliance with Legal and Ethical Standards: The system should be continuously evaluated against evolving laws and ethical frameworks governing AI use in the criminal justice system, aligning practices with international human rights standards and national regulations.

3. Testing & Results Discussion

To empirically validate our choice of an LLM for Optical Character Recognition (OCR), we conducted a comprehensive evaluation using the system we developed. The primary objective was to perform a head-to-head comparison of Google's Gemini Flash 2.0 and OpenAI's GPT-4o models. The testing was executed on the testing_data split of the FUNSD dataset, which comprises 50 distinct scanned documents, representing a realistic sample of administrative and form-based paperwork.

The evaluation process, as captured in the terminal screenshots, involved running our main script (npm start) to process all 50 test documents. As the script initiated, it first loaded the dataset, confirming the 50 documents were ready for processing. The core of the evaluation was the simultaneous processing loop, where for each document, both Gemini and OpenAI models were invoked in parallel. This methodology is crucial as it ensures a fair and direct comparison by having both models analyze the exact same document under identical conditions. The terminal output clearly shows this process in action, logging the real-time Character Error Rate (CER) and processing time for each model on a per-document basis. A deliberate 3-second delay was implemented between processing each document to respect API rate limits and ensure the stability of the test run.

The complexity of the task is well-illustrated by documents like 82092117.png, a sample from the test set. This document is a fax cover sheet containing a mix of challenges for any OCR system: a company logo, varied font sizes and weights, structured form fields with questions (e.g., "TO:", "FAX NUMBER:") and corresponding answers, fine-print legal disclaimers, and header/footer information. The models needed to accurately transcribe all these different text elements while maintaining their logical relationship, which tests their robustness against real-world document noise and structural diversity.

Upon completion of the 50-document run, the system aggregated the results and generated a final comparison summary. The empirical data gathered provides a clear quantitative basis for our model selection.

Metric	**Gemini Flash 2.0**	**OpenAI GPT-4o**	**Winner**
Overall Accuracy	*83.51%*	81.50%	*Gemini*

Metric	Gemini Flash 2.0	OpenAI GPT-4o	Winner
Character Error Rate (CER)	*21.30%*	25.10%	*Gemini*
Avg. Processing Time	*5,049 ms*	11,903 ms	*Gemini*

Table 1 : Why choose Gemini over ChatGPT

The results unequivocally demonstrate the superiority of Gemini Flash 2.0 for this specific OCR task. It achieved a higher overall accuracy and a significantly lower Character Error Rate, indicating more precise text extraction. Most impressively, Gemini was more than twice as fast as GPT-4o, processing documents in approximately 5 seconds on average compared to nearly 12 seconds for OpenAI. This substantial performance gap highlights Gemini's efficiency, which is a critical factor for any scalable, real-world application where processing time and computational cost are major considerations. Therefore, based on its superior accuracy, lower error rate, and remarkable speed, Gemini Flash 2.0 was selected as the optimal LLM for our OCR solution.

Furthermore, a significant practical advantage that heavily influenced the selection of Gemini Flash 2.0 is its accessible pricing model, particularly the provision of a generous free tier. Unlike OpenAI's GPT-4o, where API usage for vision tasks is metered and incurs costs from the very beginning, Google offers a substantial free quota for Gemini API calls. This was instrumental during the development and testing phases of this project, as it allowed for extensive experimentation, repeated test runs on the entire dataset, and iterative refinement of our prompts and processing logic without accumulating significant expenses. For developers, researchers, or small-scale projects, this free tier removes a critical financial barrier, enabling thorough validation and prototyping. This cost-effectiveness, combined with its superior performance, solidifies Gemini Flash 2.0 not only as the more powerful technical solution but also as the more pragmatic and economically viable choice for developing and deploying a scalable OCR system.

4. Commercialization

Market Gap

The criminal justice system currently struggles with inefficiencies caused by manual handling of investigation data, leading to delays, errors, and overlooked critical correlations among cases. Existing tools are mostly standalone solutions addressing narrow tasks such as lie detection or basic database management, lacking an integrated AI-powered platform that combines automated data extraction, emotional and behavioral analysis, dynamic interrogation support, and multi-modal incident correlation.

A clear gap exists for a comprehensive, AI-driven investigative assistance system that dramatically improves investigative accuracy, reduces case resolution time, and enhances decision-making through real-time insights and integrations with law enforcement databases.

Value Proposition

- End-to-End AI Integration: Combines OCR, NLP, multi-modal emotion analysis, and pattern recognition to deliver a unified investigative tool.
- Efficiency Gains: Significantly reduces manual data handling, accelerating case resolution and improving investigator productivity.
- Enhanced Accuracy: Advanced LLM and multimodal AI models ensure high precision in data extraction and behavioral insights.
- Real-Time Decision Support: Dynamic questioning and emotion tracking assist interrogators in eliciting truthful and relevant information.
- Seamless Data Synchronization: Integrates with law enforcement databases to maintain updated and centralized case data.
- User-Friendly Interface: Intuitive dashboards with gamification features encourage user engagement and ease of adoption.
- Multi-Lingual and Accessibility Support: Cater to diverse user bases while complying with accessibility standards.

Target Audience

- Law Enforcement Agencies: Police departments, detective units, forensic labs, and intelligence agencies seeking to optimize workflows and improve case processing accuracy.
- Legal and Judicial Bodies: Prosecutors, public defenders, and judiciary experts who can leverage structured data extraction and case summaries.
- Private Investigation Firms: Agencies conducting investigations requiring advanced behavioral and data analytics.
- Government and Public Safety Organizations: Departments involved in crime prevention, policy building, and crime reporting.
- Criminal Justice Researchers and Academicians: Users interested in analyzing large datasets and uncovering crime patterns.
- Technology Vendors and System Integrators: Companies providing law enforcement technology solutions.

Commercialization Strategy

- Pilot Projects and Collaborations: Partner with selected police departments and forensic labs to deploy pilot versions, gather real-world feedback, and demonstrate value.
- Government and Institutional Procurement: Participate in tenders and public sector technology initiatives for law enforcement modernization.
- SaaS and Licensing Model: Offer a subscription-based cloud service with tiered pricing depending on usage, user seats, and feature access.
- Training and Certification Programs: Develop comprehensive training modules and certification tracks for investigative personnel to ensure effective adoption.
- Technology Partnerships: Collaborate with established law enforcement tech vendors for integration and co-marketing opportunities.
- Conferences and Workshops: Present the solution at criminal justice and AI conferences to build reputation and acquire leads.
- Online Presence and Thought Leadership: Maintain a strong digital presence through content marketing, webinars, whitepapers, and case studies.
- Support and Customer Success: Provide robust post-deployment support via dedicated teams to enhance customer satisfaction and retention.

Revenue Models

- Subscription Fees: Monthly or yearly SaaS subscriptions offering variable features based on plan levels (basic, professional, enterprise).
- Implementation and Customization Charges: Fees for initial setup, customization to agency workflows, and integration services.
- Training and Certification Fees: Revenue from training programs and accredited investigator certification.
- Consulting Services: Expert consulting for data management strategies, AI adoption planning, and forensic analytics optimization.
- Data Analytics Add-ons: Premium modules for advanced analytics, automated reporting, and AI model tuning.
- Government Grants and Funding: Potential funding support from public safety innovation grants.

Community Building

- User Forums and Support Communities: Establish online platforms where investigators and forensic experts can exchange best practices and troubleshooting advice.
- Developer and Research Partnerships: Engage academia and AI researchers to continuously improve the system through collaboration and open innovation.
- Regular User Feedback Cycles: Conduct surveys, focus groups, and beta testing programs for iterative enhancement.
- Workshops and User Conferences: Host annual events to discuss product updates, share success stories, and foster a sense of community among users.
- Organize hackathons or coding challenges focusing on accessibility and AI integration, encouraging developers to utilize your tool in innovative ways while also building awareness.

Future Development

- Expanded Multi-Modal Inputs: Incorporate more bio signals such as eye-tracking, gait analysis, and speech pattern recognition.
- Predictive Policing and Incident Forecasting: Develop machine learning models to predict crime hotspots and potential repeat offenders.
- Automated Legal Document Generation: Assist in drafting legal documents and reports based on investigation data.
- Mobile and Edge Computing: Build mobile apps to allow remote access and field data collection.
- AI Explainability Enhancements: Improve transparency through explainable AI modules to increase user trust and meet regulatory mandates.
- Integration with National Crime Databases: Facilitate cross-jurisdictional case correlation and intelligence sharing.
- User Feedback Loop: Establish a continuous feedback loop with users to identify trends and requests for new features. Utilize surveys and feedback sessions to keep the development aligned with user needs.

Risk Mitigation and Compliance

- Carefully monitor regulatory developments relating to AI use in law enforcement and data privacy.
- Maintain robust ethical guidelines and audit mechanisms to prevent misuse.
- Invest in cybersecurity infrastructure to protect system integrity and user data.

5. Conclusion

This research successfully developed and implemented an AI-assisted automated data collection and management system designed to transform the handling of criminal investigative documents. By leveraging state-of-the-art Large Language Models and multimodal AI, the system overcomes the limitations of traditional OCR- and NLP-based approaches, especially in processing unstructured, multilingual police reports and court orders without costly preprocessing. The integration of Google Gemini 2.0 Flash proved critical in achieving high accuracy, low error rates, and rapid processing speeds, outperforming comparable models such as OpenAI's GPT-4o on real-world test data.

The solution's modular design enables seamless ingestion, intelligent extraction, contextual analysis, and real-time synchronization with secure databases, while a user-centric dashboard facilitates investigators' navigation and interpretation of complex case data. The inclusion of structured data extraction across over two dozen legal fields, combined with AI-driven predictive analytics, enhances investigative efficiency and supports timely, evidence-based decision-making. Legal and ethical considerations such as data privacy, access control, and bias mitigation were rigorously addressed, ensuring the system's suitability for deployment within sensitive law enforcement environments.

This project fills notable gaps in existing literature by advancing multilingual, end-to-end document understanding and combining information extraction with outcome prediction in criminal justice workflows. The developed platform offers strong potential for commercialization and scalable adoption across law enforcement agencies, judicial bodies, and forensic practitioners. Future enhancements envision expanded multimodal biometric inputs, mobile integration, explainable AI modules, and cross-jurisdictional data collaboration. Overall, this work demonstrates the transformative potential of AI in modernizing criminal investigations, improving accuracy, reducing delays, and supporting justice through technological innovation.

6. References

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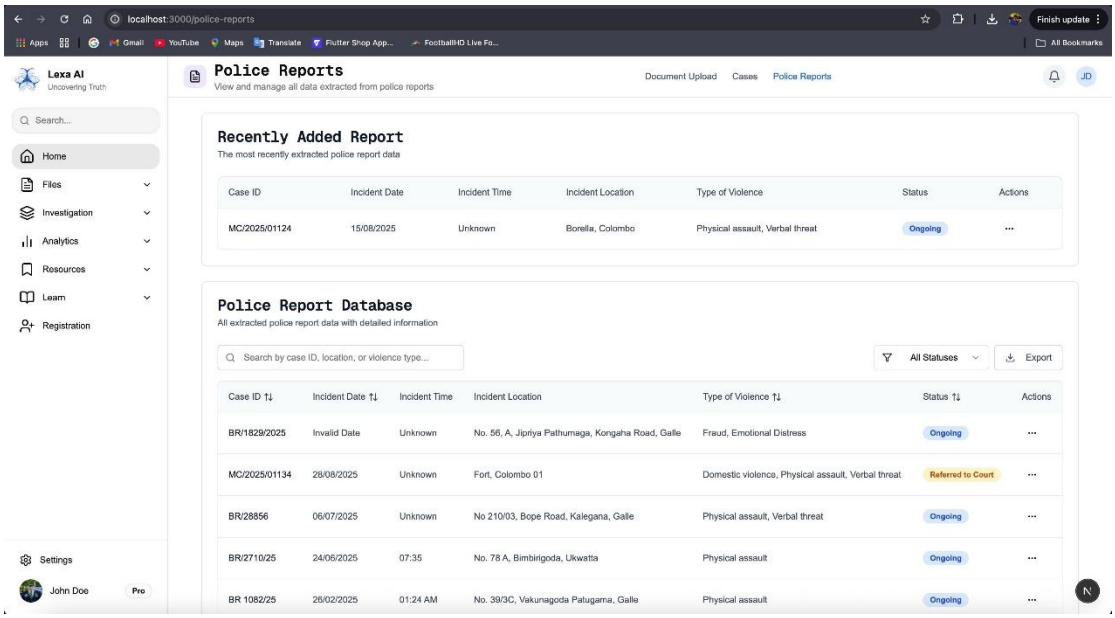
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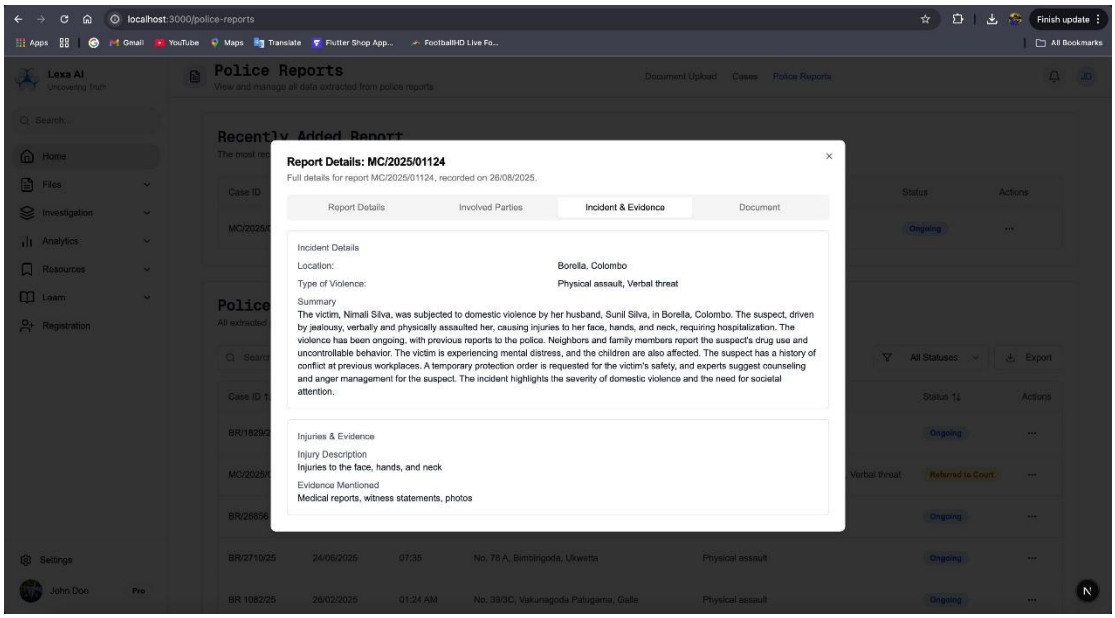
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Appendix

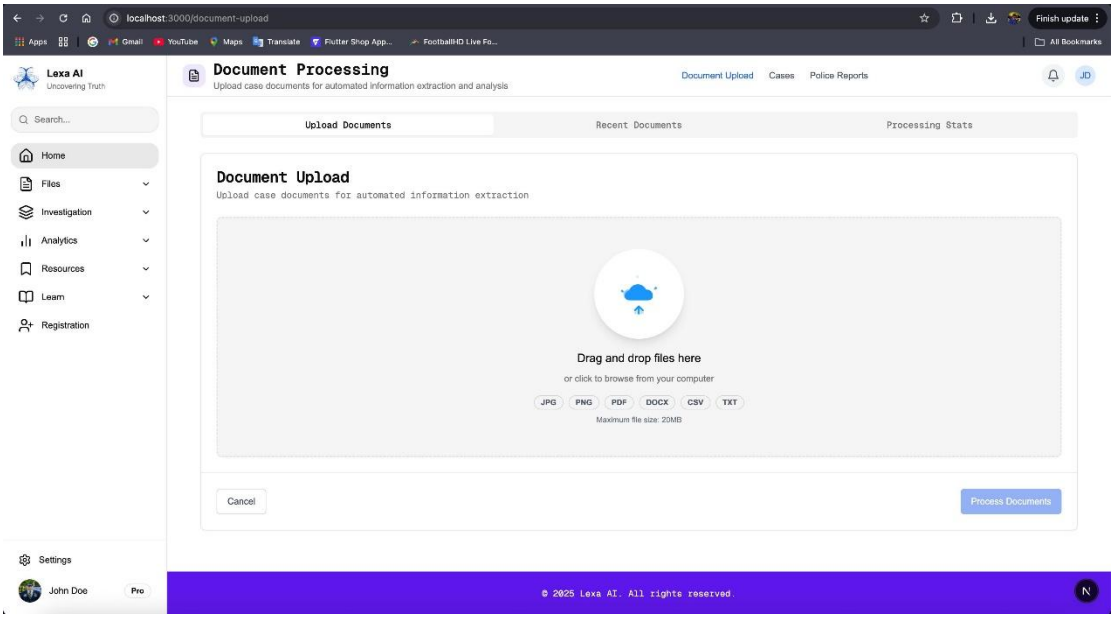
Police Report



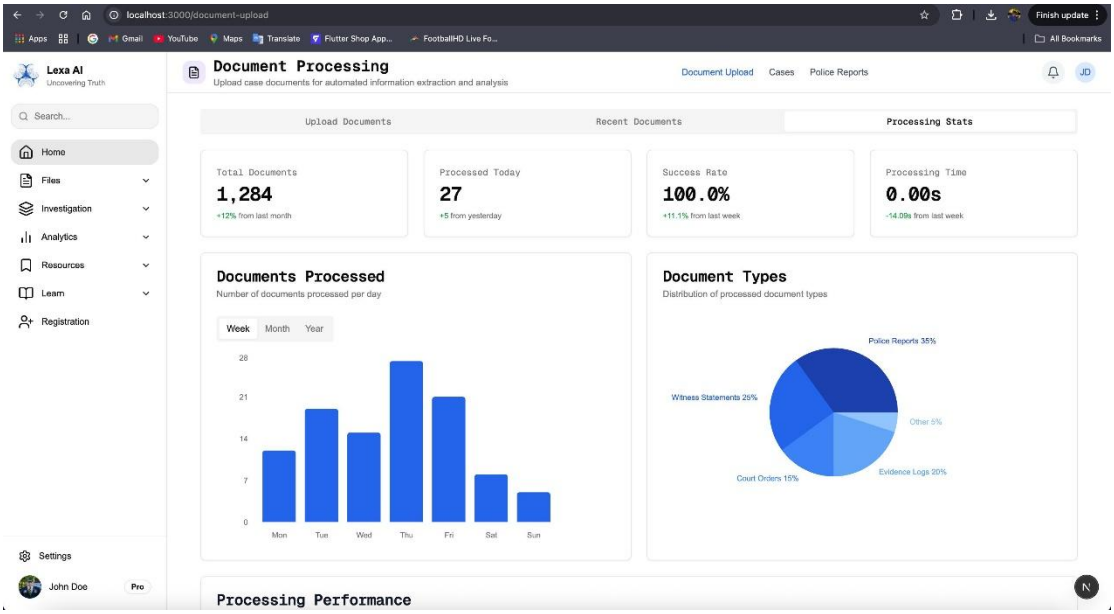
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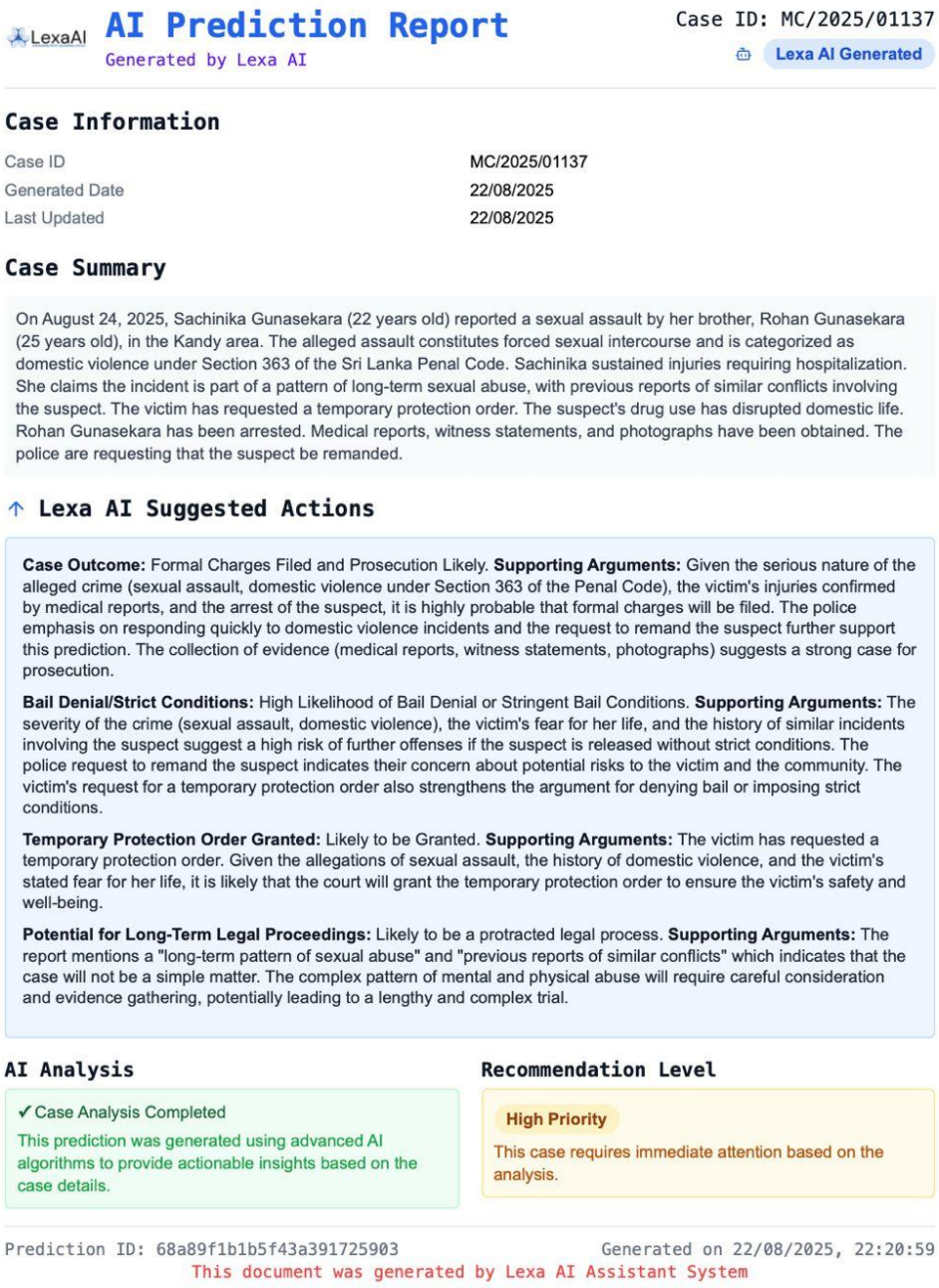
Document Dashboard



Document processing Stats



Predictions



LexaAI

AI Prediction Report

Generated by Lexa AI

Case ID: MC/2025/01137

Lexa AI Generated

Case Information

Case ID	MC/2025/01137
Generated Date	22/08/2025
Last Updated	22/08/2025

Case Summary

On August 24, 2025, Sachinika Gunasekara (22 years old) reported a sexual assault by her brother, Rohan Gunasekara (25 years old), in the Kandy area. The alleged assault constitutes forced sexual intercourse and is categorized as domestic violence under Section 363 of the Sri Lanka Penal Code. Sachinika sustained injuries requiring hospitalization. She claims the incident is part of a pattern of long-term sexual abuse, with previous reports of similar conflicts involving the suspect. The victim has requested a temporary protection order. The suspect's drug use has disrupted domestic life. Rohan Gunasekara has been arrested. Medical reports, witness statements, and photographs have been obtained. The police are requesting that the suspect be remanded.

↑ Lexa AI Suggested Actions

Case Outcome: Formal Charges Filed and Prosecution Likely. **Supporting Arguments:** Given the serious nature of the alleged crime (sexual assault, domestic violence under Section 363 of the Penal Code), the victim's injuries confirmed by medical reports, and the arrest of the suspect, it is highly probable that formal charges will be filed. The police emphasis on responding quickly to domestic violence incidents and the request to remand the suspect further support this prediction. The collection of evidence (medical reports, witness statements, photographs) suggests a strong case for prosecution.

Bail Denial/Strict Conditions: High Likelihood of Bail Denial or Stringent Bail Conditions. **Supporting Arguments:** The severity of the crime (sexual assault, domestic violence), the victim's fear for her life, and the history of similar incidents involving the suspect suggest a high risk of further offenses if the suspect is released without strict conditions. The police request to remand the suspect indicates their concern about potential risks to the victim and the community. The victim's request for a temporary protection order also strengthens the argument for denying bail or imposing strict conditions.

Temporary Protection Order Granted: Likely to be Granted. **Supporting Arguments:** The victim has requested a temporary protection order. Given the allegations of sexual assault, the history of domestic violence, and the victim's stated fear for her life, it is likely that the court will grant the temporary protection order to ensure the victim's safety and well-being.

Potential for Long-Term Legal Proceedings: Likely to be a protracted legal process. **Supporting Arguments:** The report mentions a "long-term pattern of sexual abuse" and "previous reports of similar conflicts" which indicates that the case will not be a simple matter. The complex pattern of mental and physical abuse will require careful consideration and evidence gathering, potentially leading to a lengthy and complex trial.

AI Analysis

✓ Case Analysis Completed

This prediction was generated using advanced AI algorithms to provide actionable insights based on the case details.

Recommendation Level

High Priority

This case requires immediate attention based on the analysis.

Prediction ID: 68a89f1b1b5f43a391725903

Generated on 22/08/2025, 22:20:59

This document was generated by Lexa AI Assistant System

Police reports

LexaAI

Police Report

Generated by Lexa AI

Case ID: BR/28856

Ongoing

Report Information

Report Date	23/07/2025
Incident Date	06/07/2025
Incident Time	Unknown
Location	No 210/03, Bope Road, Kalegana, Galle

Perpetrator Information

Name	Ukwatta Durage Thushara Jayasekara
Gender	Male
Nationality	Unknown
Relationship to Victim	Spouse

Victim Information

Name	Pavitra Lakmini Ariyaratne
Age	Unknown
Gender	Female
Nationality	Unknown

Case Details

Type of Violence	Physical assault, Verbal threat
Recurrence	Repeat incident
Prior Criminal History	Unknown

Incident Summary

Pavitra Lakmini Ariyaratne reported to the Galle Children and Women's Bureau that her husband, Ukwatta Durage Thushara Jayasekara, frequently harassed and assaulted her, causing mental distress and domestic violence. The police summoned both parties, recorded statements, and initially reconciled them. However, Pavitra reported further incidents on 2025.07.07, stating that her husband, under the influence of alcohol, verbally abused and assaulted her. Due to continued physical and mental abuse, authorities decided to take action under the Domestic Violence Prevention Act No. 34 of 2005.

Injury Description

Unknown

Evidence

Affidavit

Action Taken

The parties were summoned to court on 2025.08.23 and signed bonds. The suspect was advised to not harass the victim.

Relevant Laws

Domestic Violence Prevention Act No. 34 of 2005