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PRIVACY-PRESERVING LICENSE PLATE ANALYSIS IN CROSS-BORDER CITIES: A CASE STUDY OF SŁUBICE – FRANKFURT (ODER)

Metering systems are used in numerous scenarios, and their technical properties are often influenced by non-technical factors resulting from data collection and processing. This phenomenon is particularly important in cross-border cities, where significant fluctuations in traffic volume are observed, and its analysis requires continuous monitoring of vehicle flows while simultaneously considering legal constraints related to privacy protection. This paper presents the concept of a traffic monitoring system based on sensor network nodes equipped with cameras and edge computing mechanisms, in which vehicle detection and license plate recognition are performed locally using artificial intelligence algorithms. Furthermore, an analysis of legal approaches in both countries was conducted, indicating that in practice, it is necessary to design systems in accordance with more restrictive regulations, leading to the use of local processing, data minimization, and information aggregation.

ANALIZA TABLIC REJESTRACYJNYCH Z UWZGLĘDNIENIEM OCHRONY PRYWATNOŚCI W TRANSGRANICZNYCH MIASTACH: STUDIUM PRZYPADKU SŁUBICE–FRANKFURT NAD ODRĄ

Systemy pomiarowe znajdują zastosowanie w wielu scenariuszach, a na ich właściwości techniczne często wpływają czynniki nietechniczne wynikające z faktu gromadzenia i przetwarzania danych. Zjawisko to jest szczególnie istotne w miastach transgranicznych, gdzie obserwuje się duże wahania natężenia ruchu drogowego, a jego analiza wymaga ciągłego monitorowania przepływów pojazdów przy jednoczesnym uwzględnieniu ograniczeń prawnych związanych z ochroną prywatności. W pracy przedstawiono koncepcję systemu monitorowania ruchu opartego na węzłach sieci sensorowych wyposażonych w kamery oraz mechanizmy przetwarzania brzegowego, w którym detekcja pojazdów i rozpoznawanie tablic rejestracyjnych realizowane są lokalnie z wykorzystaniem algorytmów sztucznej inteligencji. Ponadto przeprowadzono analizę podejść prawnych w obu krajach, wskazując, że w praktyce konieczne jest projektowanie systemów zgodnie z bardziej restrykcyjnymi regulacjami, co prowadzi do stosowania przetwarzania lokalnego, minimalizacji danych oraz agregacji informacji.

1. INTRODUCTION

Traffic measurement systems used in cross-border cities must account for their specific dynamics, resulting from the daily connections between neighboring countries. In such areas, significant traffic volume variability is observed, depending on working hours, differences in the operation of public services, and economic factors. Daily commuting, involving both employees and service users, is a particularly significant phenomenon. Consequently, there is a growing need for in-depth analysis of these processes, both from the perspective of transport planning and urban infrastructure management.

At the same time, effective road traffic monitoring requires access to data that allows for the analysis of vehicle movements and the identification of recurring patterns. In practice, this means processing vehicle information, including license plate data. While this data does not always allow for direct identification of an individual, in certain circumstances it can lead to indirect identification. As a result, a significant conflict arises between the usefulness of monitoring systems and the need to ensure privacy protection and compliance with applicable laws.

The purpose of this article is to compare the legal approaches to the processing of license plate data in Poland and Germany. Furthermore, a data processing scenario was presented that can be considered

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acceptable from both an organizational and legal point of view, while maintaining the usefulness of the system in the analysis of cross-border traffic.

2. STATE OF THE ART

Modern road traffic monitoring systems increasingly utilize image analysis, with cameras serving as a primary source of data on vehicle flow. Compared to traditional methods, they enable the acquisition of information not only on the number of vehicles but also their directions. Automatic license plate recognition (ANPR) plays a significant role, enabling the identification of repetitive journeys and the analysis of mobility patterns. These solutions are being intensively developed using deep learning methods such as complex neural networks (CNNs) and object detection models such as YOLO [1].

In parallel, privacy-sensitive approaches to monitoring systems are being developed. Data minimization and privacy by design principles, which assume limiting the scope of processed information at the system design stage, are crucial. Local processing (edge computing) is also increasingly used to limit the transmission of raw video data [2]. These approaches are complemented by anonymization and pseudonymization techniques, which aim to reduce identification risks but do not guarantee privacy due to the possibility of re-identification [3].

Despite technological progress, a research gap remains apparent. Most work focuses on improving detection and recognition performance, while less attention is paid to legal compliance. This is particularly important given the varying interpretations of license plate data across European countries, despite the existence of a common legal framework [4].

3. LEGAL APPROACH TO COLLECTING AND PROCESSING LICENSE PLATE DATA IN POLAND AND GERMANY

From the perspective of Polish law, the processing of license plate data should be analyzed primarily in the context of the General Data Protection Regulation (GDPR) [5] and the Personal Data Protection Act of 10 May 2018 [6]. A key issue is determining whether a vehicle registration number constitutes personal data. According to the definition in the GDPR, personal data is any information relating to an identified or identifiable natural person. In practice, this means that a registration number can be considered personal data if it can be linked to a specific vehicle owner, for example, through access to relevant registers.

The Personal Data Protection Office (UODO) adopts a broad interpretation in this regard, although administrative court rulings have diverged. Therefore, a precautionary approach is adopted in the design of traffic monitoring systems, assuming that license plate numbers are treated as personal data. This requires compliance with all GDPR requirements, in particular, an appropriate legal basis for data processing, most often in the form of fulfilling a task in the public interest.

As a consequence, traffic monitoring systems using license plate data can be implemented in Poland, provided they are properly designed in accordance with the principles of privacy by design and ensure compliance with the requirements of the GDPR.

In the German legal system, the processing of license plate data is subject to the provisions of the General Data Protection Regulation (GDPR), supplemented by the Federal Data Protection Act (Bundesdatenschutzgesetz, BDSG [7]) and constitutional regulations resulting from the Grundgesetz. Of key importance is the concept of the right to information self-determination (informationelle Selbstbestimmung), developed in case law, which sets a very high standard of data protection and, in practice, significantly limits the possibilities of using monitoring systems based on vehicle identification.

In Germany, a broad interpretation of personal data is adopted, according to which a license plate number constitutes personal data if it can even potentially be linked to a specific individual. Consequently, even pseudonymous processing of license plate numbers, for example, using a hash

function, can be considered personal data processing if it enables the tracking of a vehicle between measurement points.

A key element of the German approach is the strong embedding of data protection in constitutional law. The Federal Constitutional Court (Bundesverfassungsgericht) has repeatedly stated that automatic license plate recognition constitutes an interference with fundamental rights and requires a clear statutory basis and compliance with the principle of proportionality. In particular, mass, indiscriminate monitoring of all road users without a specific justification related to public safety is unacceptable.

In practice, this means that systems enabling the identification or tracking of vehicles between different points, even when using pseudonymization, may be deemed illegal, especially in federal states like Brandenburg, where similar solutions have already been challenged by supervisory authorities and courts. The lack of a clear legal basis for such applications in the context of traffic analysis makes their implementation in civilian environments very difficult or impossible in practice.

Consequently, only solutions with significantly limited privacy intrusion remain permissible in Germany, such as vehicle counting, traffic analysis, or fully aggregated data processing. Even in these cases, proportionality and compliance with the principles of data minimization and purpose limitation must be demonstrated, meaning that implementing such systems may still be legally challenging.

4. PRIVACY PROTECTION MECHANISMS

In traffic monitoring systems based on license plate analysis, methods that limit the possibility of identifying vehicles, and indirectly, individuals, play a key role. In practice, full data anonymization is difficult to achieve, so pseudonymization techniques are most often used, which reduce the risk of identification while maintaining data usability.

One of the basic methods is to use a cryptographic hash function, which transforms the license plate number into a unique, fixed-length identifier. To increase security, a "salt" is used, which is an additional random value added before the hashing process, making dictionary attacks and reversal of the process more difficult. Such transformed identifiers allow for the detection of repeated trips without storing the original license plate numbers.

Another approach is partial data masking, which involves removing or replacing portions of the registration number, for example, by leaving only a few characters. This method limits the possibility of unique identification, but its effectiveness depends on the level of data aggregation and the context in which it is used.

Ephemeral IDs are also used, which are assigned to vehicles for a short period and change cyclically. This approach allows for the analysis of short-term traffic patterns while preventing long-term tracking of specific vehicles.

Data aggregation, which analyzes aggregate statistics rather than individual events, complements the above methods. For example, instead of recording individual trips, the system can store the number of vehicles in a given time period or direction of travel. This approach significantly reduces the risk of re-identification.

5. APPLICATION SCENARIO: SŁUBICE AND FRANKFURT (ODER)

Implementing a traffic monitoring system in the Słubice–Frankfurt (Oder) area requires both alignment with real traffic infrastructure and compliance with the most restrictive legal framework, particularly on the German side. Measurement points should be placed at key entry and exit routes reflecting actual traffic flows. The primary location is the city bridge (Stadtbrücke), which carries daily cross-border traffic. Additional points should be located on main access roads, such as ul. Kościuszki and ul. Transportowa in Słubice, and Karl-Marx-Straße or Slubicer Straße in Frankfurt (Oder), as well as on routes connecting to the A2 (Poland) and A12 (Germany) highways. A critical location is the

Świecko border crossing, which handles significant transit and freight traffic. In total, the system should consist of approximately 6–8 strategically placed stations covering urban, regional, and transit flows.

From a legal perspective, the system must avoid any functionality enabling identification or tracking of individual vehicles between measurement points, as such approaches are not acceptable under German regulations. Therefore, pseudonymization mechanisms allowing cross-point correlation, such as hashing-based identifiers, should not be used. Instead, AI video stations should operate using edge computing, limiting processing to vehicle detection, direction of travel, travel time, and basic characteristics such as vehicle type. If license plates are processed, only limited information such as regional prefixes may be extracted, with the remaining data immediately deleted and never stored.

The system should operate on aggregated data, such as vehicle counts, flow directions, and regional traffic distribution. Processing must be performed locally, without storing raw video or full license plate numbers. This approach ensures compliance with data minimization and eliminates the possibility of tracking individual vehicles, while still enabling meaningful analysis of cross-border traffic patterns.

To ensure the proposed system is legally compliant, a minimum set of requirements must be met. A data protection impact assessment (DPIA) must be conducted to assess risks and define safeguards. The system must comply with the disclosure obligation, clearly informing individuals about the monitoring and its purpose, and the data controller must be clearly identified. Data retention policies should specify limited retention periods, with data being deleted as soon as it is no longer needed, and access control mechanisms must limit access to data to authorized personnel. Furthermore, an appropriate legal basis for processing must be established, such as a task carried out in the public interest. Finally, the system must comply with the principle of proportionality, ensuring that the scope of data processing is strictly limited to what is necessary.

6. CONCLUSIONS

Legal feasibility of cross-border traffic monitoring differs significantly between Poland and Germany. In Poland, systems based on pseudonymization and limited vehicle tracking are possible under GDPR, provided appropriate safeguards such as data minimization, short retention, and a valid legal basis are ensured. In contrast, the German approach, particularly in Brandenburg, is much more restrictive. Solutions enabling identification or tracking of vehicles, even in pseudonymized form, are likely to be considered disproportionate. In practice, only aggregated data processing, such as vehicle counting or flow analysis without persistent identifiers, is feasible.

Therefore, cross-border systems should be designed according to the stricter legal framework, focusing on aggregation and minimizing identifiability.

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