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Patterns of exchange of forensic DNA data in the European Union through the Prüm system

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ABSTRACT

This paper presents a study of the 5-year operation (2011–2015) of the transnational exchange of forensic DNA data between Member States of the European Union (EU) for the purpose of combating cross-border crime and terrorism within the so-called Prüm system. This first systematisation of the full official statistical dataset provides an overall assessment of the match figures and patterns of operation of the Prüm system for DNA exchange. These figures and patterns are analysed in terms of the differentiated contributions by participating EU Member States. The data suggest a trend for West and Central European countries to concentrate the majority of Prüm matches, while DNA databases of Eastern European countries tend to contribute with profiles of people that match stains in other countries. In view of the necessary transparency and accountability of the Prüm system, more extensive and informative statistics would be an important contribution to the assessment of its functioning and societal benefits.

1. Introduction

The European Union (EU) has invested in the creation of a system for the transnational exchange of forensic data between Member States for the purpose of combating cross-border crime, terrorism and illegal migration: the so-called Prüm system [1,2]. This system relies on the permanent and automated exchange of information (specifically DNA profile data, fingerprints and vehicle registration data) between Member States. This paper focuses on the exchange of DNA data insofar as the Prüm Decisions have widened the scope of DNA profiling and databasing as an increasingly important tool for criminal investigation and criminal justice systems [3,4].

Although the implementation of the Prüm system has not been as fast and smooth as expected [5], according to the DAPIX[1] report issued in May 2016 [6], there are 22 operational Member States exchanging DNA data. The following six Member States have not initiated DNA data exchange: Croatia, Denmark, Ireland, Italy, Greece and the United Kingdom.

The Prüm system for exchanging DNA data consists of sending through a secure communications infrastructure (sTESTA) the profiles that comply with the Prüm matching rules, on a hit/no hit basis (Step 1).[2] Only the hits or matches that are confirmed by both parties allow additional information to be requested through the existing mutual assistance channels (Step 2). If deemed relevant, the results of the information request can then be forwarded to the authorities responsible for the criminal case concerning the match [1,7].

Nevertheless, the automated comparison of DNA profiles has increased the possibility of false positives and false negatives given the volume of profiles that are available for comparison [7–9]. In spite of the Prüm matching rules and the upgrade to the European Standard Set (ESS)-loci[3] that could mitigate this risk and an eventual re-testing to confirm matches, there are a number of profiles in older databases

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[1] DAPIX is the name of the "Working Party on Data Protection and Information Exchange". This body is mandated to overview and support the tasks and procedures related to the implementation of legislation and policies on information exchange and the protection of personal data in the context of the so-called Prüm Decisions (2008/615/JHA and 2008/616/JHA) and the "Swedish Initiative" [49]. DAPIX works in close cooperation with EUROPOL in promoting cross-border information exchange and is responsible for the implementation of the European Information Management System (IMS) and IMS Action Lists, as well as the regular update and revision of the Law Enforcement Information Exchange Manual.

[2] The automatic hits or matches generated through mass comparisons in the Prüm system were defined in Decision 2008/616/JHA [2] and classified according to their quality. A Quality 1 match (full match) occurs when all allele values of the compared loci commonly contained in the requesting and requested DNA profiles are the same. A Quality 2 match is also equal in all compared alleles but with a wildcard. That is, the compared profile counts as a match when it is equal in six loci, plus the extra allele that can be different. As such, and given the amount of profiles exchanged, Quality 1 and Quality 2 matches reported in the DAPIX statistics can include false positive (or adventitious) matches. For a discussion on Prüm matching rules and examples, see van der Beek [6].

[3] Because of the different STR systems used in forensic databases in the EU, including older, smaller systems, and the increased possibility of adventitious matches involved in massive profile data exchanges, it became necessary to expand the European Standard Set (ESS) from 7 to 12 loci [9].

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that are only upgraded when they produce a match [10]. These profiles are often not included for international comparisons and, therefore, represent a missed opportunity to solve a crime [10].

Given the increasing importance of the exchange of DNA data in criminal justice systems [11,12], this paper aims to map and analyse the patterns of DNA matching between operational countries by examining the available statistics of the operation of the Prüm DNA data exchange from 2011 to 2015.

1.1. Challenges of the Prüm system: risks and benefits

A growing body of literature in the field of social sciences has focused on the institutional and political consequences of the implementation and development of the Prüm system and the associated exchange of forensic information among EU Member States [13–19]. One topic of debate has been the differentiations in power, interests and trust among the Member States and how these aspects could bring implications in the Prüm system, as well as the consequences for the wider processes of European integration [14,17]. Dimensions related to privacy and data protection issues raised by Prüm have also been the subject of analysis, mainly referring to the implementation of common minimal standards of data protection under Prüm and the diversity of legal frameworks in EU Member States [20–23]. The obligatory nature framed by the so-called Prüm Decisions [1,2] meant that all legislative differences and locally nuanced policies and practices[4] associated with DNA profiling and databasing are now to be considered in a wider context, beyond the nation state [24–28].

The social, legal, ethical, economic and operational challenges associated with the exchange of forensic bioinformation were the subject of several works by McCartney and colleagues [8,29–31]. These offer insights into the multifaceted and complex issues of transnational cooperation in police and forensic matters, reflecting on the impacts in terms of the Prüm system's technical viability, democratic legitimacy and acceptability in view of its socioeconomic costs and benefits. As discussed by Fiodorova [26] and Prainsack and Toom [5], all the necessary procedures to implement and ensure the operation of the Prüm system impose costs (i.e., technical, financial and organisational costs) to Member States that are unequally distributed. This is evidenced in the responses to a questionnaire issued by the Belgian Presidency of the Council of the EU in 2010 that was sent to all Member States that had not yet fully completed the implementation of the "Prüm Decisions." The issues identified by the respondents as hampering the implementation of DNA exchange were mainly information technology (IT)-related, but they were also associated with financial matters and human resources [32]. Moreover, besides legal and operational challenges, many EU countries are facing economic difficulties that limit the availability of resources that can be dedicated to the implementation or standardisation of systems for sharing forensic information [8,29].

In spite of critical voices, the potential benefits and advantages of the Prüm system have been highlighted in view of the criminal investigation intelligence it can offer in articulation with other sources of information [33]. More recently, the implementation, evaluation and strengthening of the structures for the exchange of DNA data in Prüm were the subject of a research project that focused on the cases of Belgium, France, the Netherlands and the United Kingdom. The PIES[5] project resulted in particularly relevant studies of cross-border matches between Belgium and the Netherlands [12], as well as between the Netherlands and 18 other operational Member States [34]. These and other works [35–37] have used data about confirmed matches to map the geographical patterns of crimes solved with DNA intelligence obtained through the Prüm exchange. The conclusions of these studies emphasise the notion of a "proximity effect" in relation to cross-border criminality. That is, the selected location to commit a crime is usually close to the offender's residence, and the same effect can be observed in contiguous regions in spite of national borders [12,34,37].

Considering the wider implications of the Prüm DNA exchange, Wilson problematised and evaluated the Prüm model for forensic biometric cooperation in view of its contribution to the production of global public good(s) [38]. The author argues that its contribution towards the production of a global public good derives from the way in which it respects national political and legal autonomy over the regulation and use of sensitive personal data. The stability of the Prüm system will depend on its supervision and accountability to both EU and national institutions.

However, Wilson [38] also points out that the present statistical model[6] is unsatisfactory. In view of the necessary transparency and accountability of the Prüm system, more extensive and informative statistics would be an important contribution to the assessment of the system's functioning and societal benefits. Specifically, there is not much information about what Wilson refers to as "public bads," like cross-border offences. In this regard, the author questions if the asymmetrical distribution of power in the EU results in pressure for the weaker members to internalise the costs of crime. In the words of the author: "*Does the Prüm legislation oblige states of (migratory) origin to undertake the cost of databasing criminal justice information for the benefit of destination states? In other words, does it force the internalisation of externalities?*" [38].

This question seems to highlight an asymmetrical proportion of contributions (namely, the inclusion in DNA databases of known criminal offenders) and the collection of benefits (obtaining information to solve crimes) between the founding members of Prüm and the countries that joined the system through the EU Council Decisions. By resorting to the statistical data made available by DAPIX, we aim to provide an overall assessment of the current scenario and patterns of operation of the Prüm DNA exchange, highlighting the differentiated contributions by the EU Member States.

2. Materials and methods

The data collected for the analysis in this paper refer to the annual reports designed according to the form detailed in document 14103/11 [39]. This determines the format of the match statistics that Member States should report to DAPIX. Match statistics are to be issued annually and include the total number of profiles of people and stains at the beginning and end of the year in the national DNA database, as well as the total number of profiles sent and received. However, the number of profiles received from other countries is not available in countries that use CODIS (Combined DNA Index System) software, as this system only keeps statistics on the number of matches. Another table describes the match statistics of each country with its respective exchanging Member States. The columns on the table for each operational Member State include the following: total, stain own-person ex, stain own-stain ex, person own-stain ex, person own-person ex, where "own" means in

[4] For an overview of the legislative differences in forensic DNA databasing, see Santos et al. [41] and Wallace et al. [50].

[5] PIES – The Prüm Implementation, Evaluation and Strengthening of Forensic DNA Data Exchange.

[6] In 2011, DAPIX initiated the discussion of proposals for the publication of common statistics on DNA data exchange. The Dutch delegation proposed three options for the presentation of DNA exchange statistics, according to the following models: 1) the number of investigations aided, 2) the number of results that could aid an investigation (i.e., relevant results) and 3) "unfiltered" statistics counting all matches. For reasons explained in document 12226/11 [47] regarding the proposal for common statistics on DNA data exchange, Option 1 would be unviable because it would be impossible to acquire such information in most Member States and to acquire this information in a useful time period. Although the Commission expressed preference for Option 2, most Member States (15) voted for Option 3, that is, "unfiltered" statistics, which is arguably the least useful model, albeit the most feasible one. The contents of Option 3 relate the following information: all unique Quality 1 and 2 matches (sorted by country and match type), only matches based on outgoing requests (to prevent duplicate counting), the number of unique profiles sent and received in the reporting year, the number of profiles in the DNA database at the start and the end of the year and an explanation of the meaning of the data [39,47].

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the national database and "ex" refers to external or in other countries' databases.

While person-to-stain matches are undoubtedly important for criminal intelligence, the other types of matches can also constitute relevant information. For example, person-to-person matches can help in ascertaining the identity of someone who is included in more than one DNA database. Stain-to-stain matches can also provide significant criminological data on the activities of an individual or group of individuals that have left biological traces at crime scenes in multiple jurisdictions. In this paper, we chose to analyse person-to-stain matches since these are potentially more informative for the investigation of criminal offences.

After collecting the documents and any corrections and/or amendments for 2011 through 2015, the data were compiled in Microsoft Excel™ tables divided by year and country. In order to calculate figures like the "proportion of population" included in national DNA databases or the "ratio of national/Prüm matches," additional columns of information from national DNA databases were added to the tables (e.g., total country population, total number of individuals included in national databases and number of person-stain matches). These data were collected for the same years under analysis from the European Network of Forensic Science Institutes (ENFSI) annual reports published on the ENFSI's website.

There are, however, several caveats to the data collected by DAPIX. For example, Member States that use CODIS as the DNA database managing software do not record the number of sent profiles of people or stains. Although it accounts for unique matches, the data do not contemplate "clusters" (i.e., "*a set of matching profiles likely to originate from the same person and that corresponds to several criminal affairs*") [40], which could prove informative on the usefulness of matches. Moreover, whenever a Member State connects to others, the initial transactions may render a more significant number of matches on that first year than in the following years of operation under Prüm. For example, in 2014, Belgium began its exchange with France, resulting in 2925 stain-person matches, compared to 398 in 2015. Hence, this phenomenon appears, with more or less expression, every time a Member State establishes a new connection [29].

Given the limitations of the available data, an improved methodological scenario would contemplate statistics on the total profiles sent and received, the number of confirmed matches, the number of matches reported for follow-up, the number of actual followed-up criminal cases and statistics on the judicial outcomes of the cases. Nevertheless, it is important to study the available statistics to understand the current geographical patterns and tendencies in the operation of the DNA data exchange in Prüm.

3. Results

In May 2016, all Member States were exchanging DNA data with others, except for Denmark, Croatia, Greece, Ireland, Italy and the UK [6]. Some countries have been more proactive in establishing connections and have succeeded in starting exchanges with more countries. The countries with the least established connections were Belgium (with France and the Netherlands) and Portugal (with Austria, the Czech Republic, the Netherlands and Spain). The Netherlands (21), Austria (20) and Slovakia (19) are currently exchanging DNA information with the most Member States.

An overview of the available data (for 2011 to 2015) suggests that most of the volume of exchanges and DNA profile matches have occurred in West and Central European countries that have taken lead roles in the implementation of Prüm. Consistently, the top five countries in volume of Prüm matches are Germany, Austria, Spain, France and the Netherlands. Also, a rapid implementation of Prüm in the Northern and Eastern European countries contrasts with the slower development in Southern Europe countries, such as Greece, Italy and Croatia, which are not yet operational in Prüm, or Portugal, Malta and Cyprus, which have relatively small DNA databases that include less than 0.1% of the population. This is an indicator of the asymmetrical development in the implementation of national DNA databases in the EU.

Table 1
Top countries ranked by total volume of matches (2011–2015).

Year	Country	OS-EP	OP-ES	Total matches	Ratio OP-ES/OS-EP
2011	Germany	3900	632	4532	0.16
	Austria	614	849	1463	1.38
	Spain	741	167	908	0.23
	France	737	0	737	0.00
	Netherlands	443	203	646	0.46
2012	Germany	4315	1967	6282	0.46
	Spain	1830	1494	3324	0.82
	Austria	622	938	1560	1.51
	Netherlands	692	529	1221	0.76
2013	Germany	4890	1650	6540	0.34
	France	1422	3685	5107	2.59
	Austria	998	1186	2184	1.19
	Spain	892	1104	1996	1.24
	Lithuania	119	1159	1278	9.74
	Netherlands	741	473	1214	0.64
2014	Germany	3529	2210	5739	0.63
	Belgium	3255	351	3606	0.11
	Austria	1486	1516	3002	1.02
	Spain	1231	989	2220	0.80
	Netherlands	881	1059	1940	1.20
	France	1577	10	1587	0.01
2015	Germany	5612	1456	7068	0.26
	France	1567	4099	5666	2.62
	Austria	1463	1526	2989	1.04
	Spain	1218	1225	2443	1.01
	Netherlands	881	826	1707	0.94

During the observational period, the DNA databases of operational Member States in Prüm with the highest proportion of population included were France[7] (2.91% in 2011 to 4.65% in 2015), Estonia (3.31% in 2013 to 3.63% in 2015) and Finland (2.43% in 2012 to 2.87% in 2015) (see Table 3).

As noted above, some Prüm Member States consistently record the highest volume of annual matches, like Germany, Austria, Spain, France and the Netherlands, ranging from an annual sum of 8286 total matches in 2011 to 19,873 total matches in 2015. However, the average for all countries in 2015 was 1180 total matches.[8] As previously stated, total match figures can be distorted, as the confirmed matches can be conservatively calculated to correspond to a third of the total matches [38]. Nevertheless, the calculation of comparative ratios can be helpful by putting the match figures in a perspective that illustrates the functioning patterns of the Prüm DNA exchange.

Table 1 ranks the countries with a higher number of yearly total matches. This table also includes the (own) person-to-(external) (OP-ES)/(own) stain-to-(external) person (OS-EP) parameter. A higher value of this ratio means that a country is contributing with people profiles from its national DNA database to identify stains in other countries, more than their crime scene stains are being identified with people in databases of other countries. This can be interpreted as an indicator of the directionality of the geographical occurrence of the matches.

The OP-ES/OS-EP ratio compensates for the differences in the total number of matches, expressing the proportion of a given country's database contribution to the identification of stains in databases of other countries. Therefore, regardless of the relatively low number of total matches, it is possible to assess the disproportion of OP-ES and OS-EP matches.

[7] The total number of individuals in the French DNA database can include duplicate profiles or multiple DNA profiles per individual.

[8] There are missing data for 2012, as France did not provide match statistics for that year.

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Table 2
Top 3 countries ranked by ratio of OP-ES/OS-EP (2011–2015).

Year	Country	OS-EP	OP-ES	Total Matches	Ratio OP-ES/OS-EP
2011	Romania	1	39	39	39.00
	Lithuania	14	47	61	3.36
	Finland	6	17	23	2.83
2012	Lithuania	28	189	217	6.75
	Latvia	11	69	80	6.27
	Romania	102	423	525	4.15
2013	Romania	1	11	12	11.00
	Lithuania	119	1159	1278	9.74
	Bulgaria	37	317	354	8.57
2014	Romania	25	345	370	13.80
	Lithuania	102	592	694	5.80
	Estonia	14	69	83	4.93
2015	Romania	55	411	466	7.47
	Lithuania	85	400	485	4.71
	Hungary	35	156	191	4.46

Thus, our analysis focused on questioning if there was evidence of a pattern associated with the differences between the types of matches. Table 2 ranks the top three Member States for each year that have the highest disproportion of person-stain matches in Prüm, given by the OP-ES/OS-EP parameter, with significant contributions from Eastern European countries. The actual reported number of OS-EP matches for Romania in 2011 was 0, and it was changed to 1 to allow division. Also, Latvia did not report data for 2013.

Another relevant aspect emerging from the analysis of the statistical data is the proportion of person-stain matches in Prüm in relation to person-stain matches in national DNA databases. This can be presented as a percentage expressing how much the operation in Prüm represents in terms of the yearly output of each national DNA database, here converted in percentage (Table 3). Both ratios are calculated in relation to the population of individuals included in national DNA databases. Given the many outliers caused by the implementation and connections with new Member States in previous years, we focus on data for 2015. This year has the most Prüm operational between countries, although Portugal and Malta only started reporting data in 2015.

Since this measure relies on both DAPIX and ENFSI information (for person-stain matches in national DNA databases), there are cases of missing data. Bulgaria has no data, as it last reported data to ENFSI in July 2009. Additionally, Malta did not report statistics for person profiles sent or received in Prüm in 2015, and it did not present matches with the stain profiles sent to other countries. For these reasons, Bulgaria and Malta are not presented in Table 3. The following table is ranked by the ratio of Prüm/national matches. Total person/stain matches and person/stain matches per person are annual figures reported on December 2015, with the exception of Lithuania and Slovenia that reported data from June 2015. The table also includes a column with a percentage of the included individuals in the national DNA database in relation to the total population of each country as reported to ENFSI at the end of 2015 [10].

By looking at the column ranking the ratio of national/Prüm matches, the data show that Portugal had the highest level of Prüm operation matches compared to the national operation matches. In 2015, Portugal's 22 person-stain matches in Prüm are weighed against the 49 person-stain matches in the national DNA database. The other top-ranking countries are Romania, Poland, Luxembourg, Lithuania and Hungary, where the total number of matches is more substantial than Portugal's. With the exception of Luxembourg, these countries have a relatively low proportion of national person-stain matches per person [10]. This contrasts with countries like Germany, the Netherlands or Sweden, which have high ratios of national person-stain matches per person and some of the lowest ratios of ratios of OP-ES in Prüm. For these countries, not discounting false positives, the Prüm DNA exchange represented 1% to 2% of the global output of the national DNA databases in 2015. It is also possible to observe that the proportion of the population included does not necessarily associate with more national or Prüm matches.

4. Discussion

The current statistical model of Prüm DNA data exchange was subjected to consultation by the participating EU Member States within DAPIX. A majority preferred to report “unfiltered” statistics, and only few were willing to organise and report figures on confirmed matches that were deemed relevant for criminal investigation [39]. While this conditions the reliability and meaningfulness of the available data, it is nevertheless imperative to start a discussion that may lead to future improvements, like the discrimination between false positives and confirmed matches. As the DAPIX consultation process on the statistical model comes to show, there are several asymmetries in the implementation of Prüm deserving careful consideration.

There are differences in the governing legislation of DNA databases and population sizes that have been covered in previous work [41],

Table 3
Ranking of countries by ratio of national/Prüm matches (2015).

Country	OS-EP (DAPIX)	OP-ES (DAPIX)	Total Prüm matches (DAPIX)	Total national person/stain matches (ENFSI)	Ratio of national person-stain per person (ENFSI)	Total individuals included in national database (2015)	% Pop included national DNA database	Ratio OP-ES/OS-EP	Ratio of Prüm/national matches
Portugal	31	22	53	49	1.1%	4664	0.05%	0.71	45%
Romania	55	411	466	994	3.1%	32,149	0.15%	7.47	41%
Poland	70	143	213	483	1.1%	42,753	0.11%	2.04	28%
Luxembourg	230	75	305	342	14.5%	2361	0.41%	0.33	22%
Lithuania	85	400	485	2563	3.4%	76,317	2.58%	4.71	13%
Hungary	35	156	191	1236	0.9%	137,661	1.38%	4.46	13%
Austria	1463	1526	2989	22,534	11.4%	197,941	2.44%	1.04	7%
Slovakia	208	210	418	4998	9.6%	51,826	0.94%	1.01	4%
Spain	1218	1225	2443	40,534	12.7%	319,837	0.68%	1.01	3%
Slovenia	100	156	256	5184	16.7%	31,003	1.55%	1.56	3%
Belgium	593	118	711	3983	11.1%	35,991	0.35%	0.20	3%
France	1567	4099	5666	142,247	4.6%	3,068,243	4.65%	2.62	3%
Czech Republic	187	444	631	19,956	11.6%	171,519	1.63%	2.37	2%
Finland	226	398	624	23,760	15.1%	157,303	2.87%	1.76	2%
Netherlands	881	826	1707	52,295	23.3%	224,669	1.32%	0.94	2%
Estonia	25	88	113	5640	11.8%	47,618	3.63%	3.52	2%
Germany	5612	1456	7068	165,762	19.5%	849,907	1.05%	0.26	1%
Latvia	20	17	37	2216	4.2%	52,541	2.63%	0.85	1%
Sweden	366	307	673	48,352	31.8%	151,931	1.54%	0.84	1%
Cyprus	22	0	22	167	40%	414	0.05%	0.00	0%

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which, along with factors like policing practices or resources devoted to crime scene examination, can influence the total number of person-stain matches obtained in DNA databases [42,43]. In the Prüm system, we can consider the geographically divergent rates of the database size and volume of data exchange to ponder patterns of mobility between Member States [44]. These may display trends extending farther than the occurrence of matches between countries sharing borders [12,34].

The data indicate a consistently high volume of annual matches by the early signatories of the Prüm Treaty, which also operate some of the older national DNA databases in Europe [45]. Particularly in the case of Germany regarding the difference between OP-ES and OS-EP, the trend is to have higher (own) stain-to-(external) person matches in Prüm than (own) person-to-(external) stain. It means that person profiles in other Member States' DNA databases are contributing to identify crime scene stains stored in Germany's database. This is an important element in view of Wilson's argument of Prüm as an intermediate input into the production of a global public good(s) [38] if Prüm's DNA matches are seen as contributing to solve crimes and increase the country's security.

Bearing in mind the potential benefits of the transnational exchange of data, one could look at the volume of matches and conclude that a high number of matches benefit the collective good of a given country by facilitating the investigation and, eventually, the resolution of crimes [38]. However, the higher volume of DNA transactions carries the risk of adding pressure on DNA database users and administrators to confirm near matches, and countries with larger databases can be burdened with adventitious matches [8,9]. Even if not all matches are pursued in Step 2 (i.e., they generate a request for further personal data and are processed by the requesting country's criminal justice system), a significant volume of intelligence can be rendered through the exchange [33,34]. Since Member States have some degree of discretion as to the selection of Step 1 matches to report, how to assess and process Quality 2 matches or what information to provide to the requesting country in Step 2, it is possible that the differences among Member States in terms of police and judicial organisation, resources and infrastructures may be reflected in the construction of mutual trust in the integrity of transnational cooperation [8,17]. These existing asymmetries in terms of overall costs and benefits derived from national contexts and the observed fluxes of DNA matches can pose a potential element of hierarchisation and fragmentation in the operation of Prüm [17,38].

Given that the data do not inform about the nationalities, places of birth or residence or types of crime or even if the matches were confirmed and actually used to advance a criminal investigation, we may look at the following two important figures: OS-EP matches and OP-ES stain matches. Among other factors, these numbers may be affected and differentiated according to local policies and priorities regarding the collection and databasing of crime scene samples, as well as by the criteria for inclusion and exclusion of profiles of individuals and crime scene stains in each country. By assessing the ratio of OP-ES/OS-EP, the geographic and criminal mobility patterns of the Prüm exchange of DNA data may then become apparent. Thus, although there is considerable cross-border volume of matches between neighbour countries [12,34,44], there is also evidence of broader patterns of mobility from Eastern European countries towards the West.

In other words, the geographic distribution of the matches, considering the origin database of the person and the location of the stain, appears to confirm previous research on patterns of criminal mobility affecting West and Central European countries, which are mostly associated with volume crime like burglaries [34,44], usually involving individuals originating from Eastern Europe [44,46]. Moreover, the scenario expressed by the total number of Prüm matches describes a centripetal tendency of the Prüm system. The available data suggest that these West and Central Europe countries, with the exception of Germany, present a balance between OP-ES and OS-EP matches.

The same cannot be said for countries like Latvia, Lithuania and Romania, which reported relatively few identified stains through matches with people included in other countries' databases. Given the relatively low person-stain matches per person in these countries' national DNA databases, their high ranking in the ratio of OP-ES/OS-EP can be an indication of their importance in the investigation of offences in other countries and not necessarily the ones with which they share their borders.

Additionally, in order to describe the relevance of the Prüm operation, we have calculated a ratio between the output of national DNA databases in their local context and in the Prüm exchange. While the Prüm/national person-stain match parameter is significant to the importance of Prüm matches for the operation of Portugal's database, the figures can be regarded as very low in the EU context. Again, with the exception of Portugal and Luxembourg, the countries at the top are Eastern European countries like Romania, Poland, Lithuania and Hungary. This tendency could be interpreted as the issue of the internalisation of externalities in the context of Prüm suggested by Wilson [38]. Specifically, this group of countries assumes the costs of gathering criminal investigation intelligence and including profiles of individuals in DNA databases for the potential benefit of other states.

5. Conclusion

This paper provides an overview of the Prüm state of affairs, showing some tendencies in the wider patterns of Prüm DNA exchange. The main highlights are the development of a core group of countries sharing a high volume of matches between them, contrasting with an eastern peripheral group whose role has been to provide the profiles of people that match stains in the core group of countries. The data allow reference to a third group, involving the southern periphery of the EU, composed of countries like Malta, Cyprus and Portugal that are currently having very little impact on the transnational exchange of DNA data.

There are known caveats and limitations to the data presented and, consequently, to the scope of this analysis. First, the data were collected from 2011 to 2015. Over the course of these years, the number of Member States exchanging DNA data grew from 12 to 22, as did the number of interconnections between them. Hence, for every new connection, there can be a high volume of matches that may not have continuity in the following years. Moreover, the number of interconnections is uneven, as several Member States have not yet established DNA exchanges with more than 10 other Member States.

Second, by calculating ratios, our analysis attempted to minimise the effects of disparate DNA database population sizes and the total volume of matches. Nevertheless, these are crude parameters, albeit a possible and tentative way of assessing the situation regarding Prüm DNA data exchange.

Third, this analysis represents a partial portrayal of the potential of the Prüm DNA exchange. This is because the data account for all of the types of matches between the profiles that were sent and received, and the current system of reporting statistics also counts potential false positives [47]. An informed assessment of the effectiveness of the DNA data exchange would consider only confirmed matches or those that could have aided a criminal investigation. Moreover, instead of a system of open information sharing, Prüm Member States have autonomy in filtering what profiles are selected for exchange, and there are no established common protocols or guidelines to do this [5].

Currently, a global assessment of the effectiveness of the Prüm DNA exchange (i.e., the confirmed matches that have aided the investigation of a crime in all participating Member States) is simply not feasible. In spite of the scarcity of data about cross-border offences and offenders or the criminal justice outcomes of Prüm matches, it is still important to stimulate a debate on the operation and distribution of results. A social sciences approach could complement future research regarding the development of Prüm by exploring the political consequences [48] and the heterogeneous characteristics of the different national contexts [5].

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Furthermore, it could be useful to have statistics on the so-called Prüm Step 2, not only for the purpose of transparency and accountability to European citizens, but also for academic research on the different countries' justice system responses to Prüm DNA hits. For example, through the integration of Step 2 procedures and results in the Prüm operations' statistical reports, it would be possible to gather information on the actual distribution of benefits across the EU in terms of types of crimes solved, police and judicial handling of Prüm matches and relevant criminological intelligence [11,12,34]. In summary, transparency, accountability and trust are fundamental elements for the development and stability of the Prüm system. A feasible and more comprehensive reporting of match statistics would be a useful step in this path.

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