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Monitoring illicit ammunition through the ballistic datasets of four European countries☆

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ABSTRACT

Few countries systematically record and publish detailed information on the types, caliber, and makes of ammunition recovered by law enforcement. This results in a lack of knowledge of the ammunition used in crime, including in the European context. This pilot study examines the utility of ballistic datasets for monitoring illicit ammunition. The ballistic laboratories of four European countries—Denmark, Germany, Sweden, and Switzerland—provided access to non-confidential subsets of their national databases, including the caliber of recovered cartridge cases as well as the year and type of incident in which they were used. The laboratories also shared images of the ammunition headstamp markings, which helped determine each cartridge case's manufacturer and—when known—year of production. The resulting dataset covers 3130 cartridge cases documented by the participating laboratories between 2015 and the first quarter of 2020. Although limited in scope—the research team did not have access to geocoded data so spatial comparisons were limited to the country level—the dataset helps generate a baseline of the main varieties of ammunition used in crime, by country and crime category, and over time.

Most of the ammunition (61 per cent) was recovered in the context of violent types of crime—homicides and assaults—for which pistol ammunition calibers were the most prominent. 610 unique headstamps were recorded, but only a small proportion of these varieties of ammunition accounted for most of the cases. All four country datasets included both foreign-made ammunition as well as cartridges produced domestically. The year of manufacture could be identified for 28 per cent of the cartridges, and at least 27 pieces of ammunition were produced in the same year that the criminal incident took place, which suggests recent diversion from licit holdings. The dataset revealed additional trends such as the criminal use of blank ammunition in all four case studies, as well as the relatively new prevalence of the 7,62 × 39 caliber—which is typically used with AK-pattern rifles—in one country. In addition to shedding new light on the types of ammunition used in crime in the European context, monitoring illicit ammunition across space and over time has the potential to support police investigations with intelligence on criminals' sources of supply.

1. Introduction

Every year law enforcement agencies collect numerous spent cartridges at crime scenes and seize thousands of rounds of ammunition. In April 2017 INTERPOL coordinated operations in 23 European states that led to the capture of 'almost 20,000 pieces of ammunition' [1]. In Sweden alone more than 3000 rounds of ammunition were seized annually in 2016 and 2017 [2]. Statistics presenting the specific types and varieties of ammunition recovered by law enforcement agencies are rarely published, however—despite the fact that such data has the potential to provide policy-relevant information on ammunition trafficking and diversion [45].

The metallic cartridge is one of the earliest and smallest disposable industrially produced items to be individually stamped. Cartridge headstamps display some of the ammunition's key characteristics, such as the caliber of the corresponding firearm. Markings can also address a need for traceability by including manufacturer and year of production codes, which have been

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documented since at least the mid-19th century.[1] In conflict and post-conflict areas UN monitoring bodies, research organizations, and war reporters have collected this information from seized and spent cartridges to generate baselines of and monitor the main types of ammunition in circulation. Analysing this data and the trends that it reveals can then help to detect both new sources of ammunition and the proliferation of very recently produced rounds—which can assist in identifying cases of non-compliance with arms and ammunition embargoes, for instance.[2]

Despite the presence of similar markings on the cartridges retrieved as part of criminal investigations and the existence of reference guides for cartridge identification, forensic examiners have rarely used this data to create a comprehensive picture of the main types of ammunition in criminal use and the possible sources of trafficking in the European context.[3] Instead, they tend to focus on the ballistics traces left by the weapon on the cartridge, which help to identify the firearm that was used in a particular incident and establish linkages with other cases where the same gun may have been fired. In short, ballistic datasets are built to solve crime rather than to understand trafficking, in spite of the fact that they contain key information that is relevant for the latter purpose.

Forensic examiners use increasingly sophisticated and computerized tools known as automatic ballistic identification systems – ABIS (hereafter referred to as ballistic systems) to analyse recovered ammunition.[4] While designed to support the solving of firearm-related crimes, ballistic systems are potentially useful for identifying trends and patterns that can support counter-trafficking and policy-making activities. Firstly, ballistic systems contain largely untapped information on a wide range of firearms being illicitly used or trafficked. This is notably true with respect to the information they help generate on missing or 'inferred' firearms—that is, firearms that were not retrieved at crime scenes, but could nevertheless be identified based on the fired ammunition's caliber and ballistic traces. Secondly, ballistic systems record high-quality images of spent cartridges' headstamps, in which manufacturer codes and other markings typically appear. Therefore, the datasets generated by these systems contain the imagery that is necessary for analysing the headstamp information, together with contextual information about the incident in which the ammunition was used.

The aim of this research is to gauge the utility of ballistics datasets for documenting and monitoring illicit ammunition. Ballistic laboratories in four countries—Denmark, Germany, Sweden, and Switzerland—agreed to take part in the study by sharing non-confidential segments of their datasets and the corresponding headstamp images.

This research provides an analysis of the collected data, with a view to assessing the utility of ammunition records compiled in ballistic datasets for efforts to understand the illicit trafficking and use of ammunition in the four European countries. It begins with an overview of methodological considerations and caveats, before moving towards a discussion of the main results. The latter include generating a general baseline of the ammunition documented in the four countries, including by caliber, manufacturer, and date of production; considering whether specific trends can be identified depending on the country, type of crime, and year of seizure; and, finally, identifying a series of additional trends and observations made during the research that go beyond headstamp analysis and provide further insights into the illicit use of firearms and ammunition in the countries under study. The article concludes with a summary of findings and lessons learned, with particular focus on opportunities to improve understandings of illicit ammunition through the analysis of ballistics datasets.

2. Methodology

Data for this report was collected from the national ballistic systems of the four countries discussed below. Two countries use the IBIS platform, while the other two use Evofinder. The study therefore illustrates the feasibility of extracting data from different ballistic systems for the purpose of analysing the cartridge case headstamps.

2.1. Denmark and Sweden

Both Denmark and Sweden use the IBIS system to maintain a digital 'Open Case File' of recovered ballistic material. Using the built-in reporting tool of IBIS Matchpoint+ , a one-page report was produced on each cartridge that contained the headstamp image and the non-confidential contextual data relevant to this project. The total numbers of cartridges reviewed were 1459 for Sweden and 603 for Denmark. Both datasets covered the period January 2015—March 2020.

2.2. Germany

Germany's Bundeskriminalamt (BKA) provided an Excel dataset of cartridge cases seized or collected at crime scenes and a zipped file containing 104 photographs of the corresponding headstamp images. These headstamp images were tagged with the reference number of the case, which made it possible for the research team to reconstruct a full dataset of headstamp markings and non-confidential contextual data on the incidents in question. This data entry process was nevertheless more time consuming than for the other countries. In total, the German dataset includes 915 records. The dataset covers ammunition entered into the BKA's Evofinder system between January 2015 and February 2020.

2.3. Switzerland

The Zurich Forensic Science Institute (FOR) uses the Evofinder system and provided access to the Swiss data by exporting the selected specimens to export files, through which the research team could access the raw data and review the headstamp images. In total, 153 cartridges were included in the Swiss dataset, which covers entries dated between April 2015 and May 2020.

2.4. General considerations

Overall, the team reviewed and organized the records of 3130 cartridges that the laboratories had processed between 2015 and early 2020 in the context of 1918 cases. Working from the headstamp images, the cartridges' manufacturers and—where available—years of production, were identified by a ballistics and ammunition expert. Once the full dataset was compiled, a second ballistics expert fact-checked all the entries. Both experts have a significant track record in ammunition identification, as well as benefited from access to several reference guides for cartridge identification [7–14], to resources dedicated to enthusiasts and

[1] For instance, the American Spencer rimfire cartridges of the 1860 s, such as those produced by Sage Ammunition Works, Connecticut, United States, between 1864 and 1869 [3].

[2] See, for instance, Small Arms Survey research and ammunition profiles undertaken in conflict and post-conflict areas [4].

[3] See, for instance Burrard [5], for an early 20th century forensic analysis of ammunition that involved the recording of headstamp markings, but did not include any discussion on the associated manufacturer.

[4] The US Federal Bureau of Investigation's Drugfire system, which was introduced at the end of the 1980 s, was possibly the first such system created with the purpose of linking drug-related shooting incidents in the Washington, DC area [6]. A few years later the Canadian company Forensic Technologies—now Ultra Electronics Forensic Technology—launched the Integrated Ballistics Identification System (IBIS) system. Evofinder, developed by ScannBI Technology, a German company, is also widely used in Europe.

collectors such as The Cartridge Trader magazine (first issued in 1955, and named the International Ammunition Association Journal since 1994), to open-source databases such as AFTE [15], AECC [16], and IAA [17], as well as to the commercial database CartWinPro [18]. In spite of these efforts, it is possible that small errors were made or that the experts could not detect forged headstamps[5] based on the available imagery. The authors are confident, however, that the ammunition was identified based on the best available knowledge and expertize, and that any errors made would not affect the analysis and general trends presented in this article.

All the ammunition included in the dataset was recovered by law enforcement agencies as pieces of evidence; that is, 'test fires' were excluded from the dataset. Sweden had the most records of cartridges, followed by Germany, Denmark, and Switzerland (Table 1).

In all four countries, the ballistic evidence collected by law enforcement agencies as part of their investigations into a range of crimes and offenses is systematically submitted to the national ballistic database of the relevant country. The dataset is therefore representative of the ammunition being used in these crimes and offenses at the national level, although with three caveats. Firstly, the dataset includes cartridges recovered in the context of open investigations,[6] and so the type of incident may change at the end of the investigation. For instance, ammunition recorded in the context of a homicide investigation may later turn out to have been used in a suicide or accident. It is therefore not possible to directly match official firearm homicide statistics with the number of homicide cases recorded in the ballistic datasets.[7] Secondly, in cases where numerous cartridges were fired by a single firearm, forensic teams may select only a sample of the spent cartridges for inclusion in the national ballistic system—typically a maximum of three (Table 1).[8] Thirdly, in such cases forensic examiners will often prioritize the inclusion of cartridges carrying well-presented traces left by the firearm. This means that in cases where multiple cartridges are recovered, examiners may tend to deliberately prioritize cartridges made of soft metal rather than steel.[9] They may also tend to exclude homemade or reloaded ammunition that could carry traces from previous discharges and reloading. While these limitations represent potential biases, some examiners noted that when perpetrators fire multiple rounds with the same weapon, the ammunition used tends to be of the same variety—although there are exceptions.[10] Regardless, it appears to be important to amend the data entry protocols of ballistic systems in order to reduce such potential biases, as some experts have already recommended.[11]

In total, 39 types of incidents—corresponding to various crimes and offenses as defined by the national authorities of the four participating countries—were identified. To allow for the disaggregation of data by type of incident, it was therefore necessary to create broader crime categories into which nationally defined types of crime could be organized. The research team therefore categorized each incident as falling under one of the following categories, which are taken from the UN Office on Drugs and Crime (UNODC) background document entitled *International Classification of Crimes for Statistical Purposes* [22]:

- acts against property;
- assaults;
- drug-related incidents;
- homicides;
- other acts[12]; and
- violation of firearms legislation.

The participating laboratories did not provide the research team with detailed location data on the criminal incidents, which at least some of them considered to be confidential information. Similarly, detailed data on the date of the incident was not available for all the countries. This article therefore only analysed differences at the country level and on a yearly basis. Carrying out more in-depth spatiotemporal analysis of this information would nevertheless be possible for laboratories that record this information—or useable proxies, such as the name of the police station submitting the evidence—in their ballistics datasets, and even between countries via a network sharing ballistic datasets as proposed by Sautier et al. [23].

In addition to the crime category, the research team compiled non-confidential data for each piece of ammunition from the laboratories' records, notably the caliber and the year in which the criminal incident occurred. Caliber designations were standardized under a 'nominal caliber' designation, based on the typology developed by the Commission internationale permanente pour l'épreuve des armes à feu portatives (CIP) [24]. For instance, "9P", "9 × 19", and "9 mm Para", which were all used in the raw data, were recorded as "9 mm Luger".

Headstamp markings—including characters in Latin and Cyrillic script, numbers, and symbols—were broken up into specific entries to record the 'manufacturer code', 'caliber stamp', 'other markings', and 'primer stamp'. The entry 'formatted headstamp marking' automatically aggregated the headstamp markings into a single cell. While this systematic approach meant that the markings were not always retranscribed in the same sequencing that appeared on the headstamp images, it provided the most efficient way of recording full headstamp information and is sufficient for trend analysis. Some manufacturer codes and symbols were challenging to record, given their unique shapes. Six cartridge cases had no headstamp markings (see Fig. 1).[13]

Table 1
Number of cartridges examined per criminal case, by country. * While the highest number of cartridges linked to a single case in the Danish dataset was five, the dataset contained one entry entitled 'recovery' that comprised 29 cartridges recovered from multiple cases.

Country	Number of cartridges	Number of cases	Average cartridges per case	Minimum	Maximum
Denmark	603	437	1.4	1	5 *
Germany	915	441	2.1	1	3
Sweden	1459	984	1.5	1	4
Switzerland	153	56	2.7	1	8
Total	**3130**	**1918**	**1.6**	**1**	**8**

[5] See, for instance, UNIDIR - Handbook to Profile Small Arms Ammunition in Armed Violence Settings [19].

[6] For two of the participating laboratories, the ballistic datasets only include open cases still under investigation, as cases for which the crime gun was retrieved get moved to a different dataset. One laboratory keeps solved cases in its open case file but highlights them as solved.

[7] Participating laboratories explained that they change the crime categorization when informed, but two of them noted that they are not systematically notified of such changes.

[8] For example, in Switzerland four specimens were integrated into the national ballistics system out of a total of 17 cartridges that had been discharged in a single case. In the other three countries, the number of processed specimens per case was generally less than three.

[9] One participating laboratory also noted favoring cartridges with unmarked primers.

[10] One participating laboratory estimated that in 90 per cent of cases, criminals use a single brand of ammunition in a shooting.

[11] For instance, recent research recommends entering between five and seven spent cartridges per firearm [20,21].

[12] Examples of crimes falling under the 'other acts' category includes terrorism, gunshot discharge, poaching, and threats.

[13] Unmarked cartridges are not a new phenomenon. Heard [25], for instance, states that '*probably the most prolific supply of clandestine ammunition has been the Warsaw Pact countries … with no markings at all*'.

Fig. 1. Example of a cartridge case with no headstamp markings (7,62 × 39); the manufacturer is unknown.

Fig. 2. Examples of headstamps for shotshell cases feature with only a basic combination of stars and '12′ in reference to the caliber (12 Gauge); the manufacturer is respectively Dan Arms Ltd (left) and unknown (right).

Fig. 3. Example of a 9 mm Luger cartridge case with a headstamp markings very rare from Povazske Strojarne (Czechoslovakia).

While existing reference tables and the expert knowledge of the research team were sufficient to identify the manufacturer in the vast majority of cases, there were important challenges with respect to specific cartridges. For instance, headstamps for shotshell cases often only featured a basic combination of stars and '12' in reference to the caliber (see Fig. 2). Some headstamps are very rare, and caused intensive discussions among the researchers and ammunition experts (see Fig. 3). Headstamps can also be forged in the case of 'imitation rounds', although no such cartridges were identified in the dataset [26].

Determining the country of manufacture based solely on headstamp markings was also difficult in some cases. For example, CBC Global Ammunition is a consortium of companies established in both the Americas and Europe, including Companiha Brasileira de Cartuchos (CBC), Magtech, MEN, and Sellier & Bellot. It can therefore be challenging to ascertain whether a cartridge case bearing the CBC headstamp was made in Brazil or Europe without being able to examine the box in which it was packed after manufacture. Another practical issue arising from the 'inferred country of manufacture' column lies in countries whose names have changed over time.[14]

In spite of these limitations, the project dataset represents the largest compilation to date of information on ammunition used in crime in the European context. It therefore demonstrates the feasibility of extracting ammunition data from ballistic systems, the utility of which will be discussed in the following sections.

Table 2
Top ten calibers for the full dataset, with cartridge counts by country.

Nominal caliber	Denmark	Germany	Sweden	Switzerland	Total
9 mm Luger	260	298	479	86	1123
7,65 mm Browning	87	245	368	20	720
7,62 × 25 Tokarev	13	35	163	4	215
9 mm PA Blanc	33	118	36	5	192
9 mm Browning court	30	37	86	1	154
7,62 × 39	20	10	97	1	128
.22 Long Rifle	35	30	39	6	110
6,35 Browning	8	57	25	8	98
9 mm Makarov	1	18	56	0	75
.45 Auto	31	11	21	6	69
Other nominal calibers	85	56	89	16	246
Total	**603**	**915**	**1459**	**153**	**3130**

3. Results and discussion

3.1. A baseline of illicitly used ammunition

Small arms ammunition can be categorized according to three main features: the caliber; the manufacturer; and, when known, the date of production. This information, while basic and relatively easily retrievable, helps to generate a general baseline of the ammunition under review that can then serve for comparing trends and patterns across countries or over time.

3.1.1. Caliber

The dataset includes a total of 48 calibers, yet only a few were prominent. In fact, the top ten calibers accounted for 92 per cent of the database (Table 2). Notably, 9 mm Luger cartridges represented 36 per cent of the dataset, followed by 7,65 mm Browning (23 per cent). In all four countries 9 mm Luger is by far the most common caliber, ranging from 33 per cent of the sample in Germany to 56 per cent in Switzerland. This pattern appears to be consistent with this caliber's dominance of the global ammunition market [27–29]. Overall, calibers associated primarily with NATO standards dominate the sample, although Sweden stood out with two Warsaw Pact standard calibers (7,62 × 25 Tokarev and 7,62 × 39) featuring in the five most prominent calibers in this dataset. 9 mm PA Blanc is present in all four countries—and in the top five calibers in both Denmark and Germany—but information on whether these rounds were modified to expel projectiles is only partial (see below).

Caliber distribution makes it possible to infer the probable categories of firearms used in the corresponding crimes. The research team assigned types of firearms to each of the 48 calibers under review, based on the weapons that each caliber is primarily associated with in the European context. For example, the.357 Magnum caliber was categorized as primarily a revolver caliber, while

[14] For instance, ammunition produced in Bosnia and Herzegovina in the 1960 s can be labeled as Bosnian or Yugoslavian. In the dataset, both the historical name of the country and its current name were kept. When the year of manufacture was unknown—as in 72 per cent of cases—the inferred country of manufacture recorded in the dataset was the current one.

Table 3
Distribution of the cartridges by inferred type of firearm.

Type of firearm	Percentage of the database
Pistols, 'self-loading pistols', and sub-machine guns	80.5 per cent
Revolvers	1.9 per cent
Rifles	4.6 per cent
Assault rifles	5 per cent
Shotguns	1.4 per cent
Gas and alarm weapons	6.6 per cent

3.1.2. Manufacturers

Although identifying the country of manufacture was subject to caveats, the manufacturer markings made it possible to identify a list of 38 countries, mainly European, where the recorded cartridges were produced. The Czech Republic, Germany, and Brazil stood out as the three main producers of the ammunition documented in the dataset (Table 4).[16] Other common countries of manufacture in the dataset included the United States, Italy, Bosnia and Herzegovina, the Russian Federation, and Denmark.

Some noteworthy common patterns appear when the manufacturing countries identified in the national-level datasets are compared. Firstly, the overall top three producers—Brazil, the Czech Republic, and Germany—also feature in the top-ten lists of all four countries. Secondly, domestically produced ammunition also ranks in the top ten in all four countries. Denmark, Germany, Sweden, and Switzerland all host or have hosted factories that produce ammunition for the military, law enforcement, and civilian markets. It is therefore likely that some of this ammunition was diverted locally to illicit use. Thirdly, ammunition produced in the Western Balkans—namely Bosnia and Herzegovina, Serbia, and the former Yugoslavia—features in the top ten of three countries, but not in Switzerland.

Headstamp markings usually include a code that makes it possible to identify the specific manufacturer or production facility. In total, 95 manufacturers were identified in the dataset. Among them, Sellier & Bellot, CBC, RWS/Geco, and Prvi Partizan are the main producers, each accounting for more than 350 cartridges in the dataset. This picture is somewhat different at the country level, notably in Sweden, where Prvi Partizan is the most common manufacturer of cartridges recorded in the national dataset (Fig. 5).

Headstamp analysis allows for a closer examination of the distribution of cartridges by ammunition variety—which is defined as a unique combination of caliber and headstamp markings. While at least 610 unique headstamps[17] were identified in the dataset, the 20

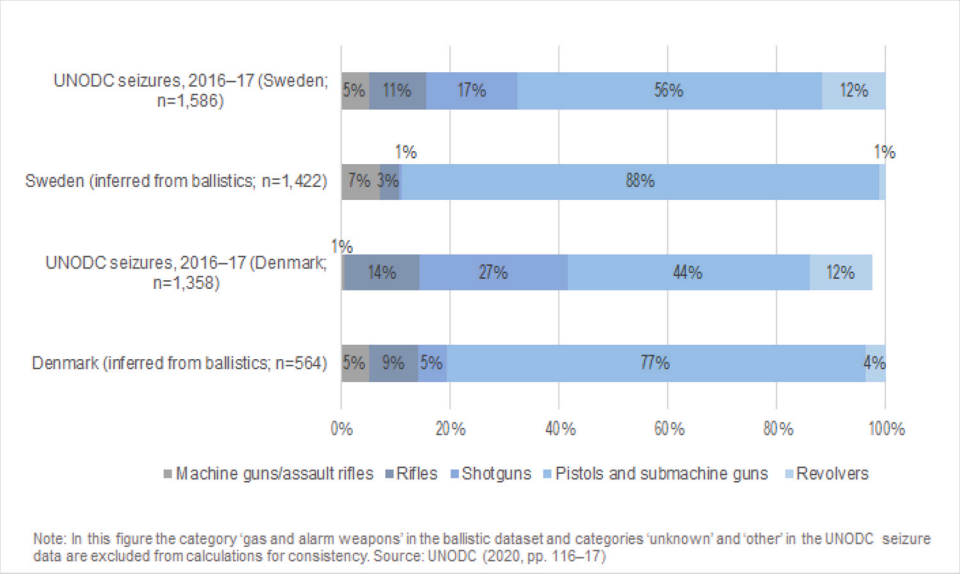

Fig. 4. Typologies of illicit firearms in Denmark and Sweden, based on ballistic datasets and UNODC seizure data.

7,62 × 25 Tokarev was associated with pistols—despite the fact that some rifles (including carbines) and some pistols can chamber the former, and some sub-machine guns can fire the latter. These caveats in mind, the distribution of the dataset by inferred type of firearm is provided in Table 3.

Ammunition calibers primarily associated with pistols account for more than 80 per cent of the sample.[15] At the other end of the range, long gun calibers—including for rifles, assault rifles, and shotguns—only account for 11 per cent of the dataset. In the cases of Denmark and Sweden, this distribution is not fully consistent with seizure data collected by UNODC. As can be seen in Fig. 4—if gas and alarm weapons are excluded from the total—handguns (that is, pistols and revolvers) represent 82 and 89 per cent of the Denmark and Sweden ballistic datasets, respectively, but only 50 and 64 per cent of recorded seizures. Shotgun ammunition appears to be particularly under-represented in the ballistic datasets of these two countries. These variations can be explained by the fact that seizures can take place in the context of a broad range of crimes and offenses that did not necessarily involve actual shootings, whereas ballistic datasets are only concerned with cases involving shootings or gun discharges. These patterns may also suggest that significant proportions of handguns were used in crime, but had not yet been retrieved or seized.

[15] The prevalence of pistols has also been observed in other developed countries. For example, in the United States, among the firearms seized by law enforcement agencies in eight US cities during the years 2007–12, '*at least 70 per cent of the seized handguns were semi-automatic pistols of various makes and models*' [30].

[16] This is consistent with international small arms trade data, as these three countries also feature among the world's top small arms exporters [31].

[17] The 610 count does not include a few cases where the caliber and factory were the same, but the fonts used were different. For instance, 'G.F.L._9mm P.A.Knall' and 'G.F.L._9mm P.A.KNALL' were counted as one headstamp, not two.

Table 4
Top ten countries of manufacture for the full dataset and by country.

Country of manufacture	Number of cartridges
Full dataset	
Czech Republic	538
Germany	525
Brazil	407
Sweden	272
Serbia	254
United States	229
Italy	160
Yugoslavia (Serbia)	104
Russian Federation	75
Denmark	67
Denmark dataset	
Germany	98
United States	68
Czech Republic	68
Brazil	67
Sweden	66
Denmark	64
Serbia	27
United Kingdom	18
Finland	17
Bosnia-Herzegovina	15
Germany dataset	
Germany	313
Czech Republic	234
Brazil	83
Serbia	38
Bosnia-Herzegovina	35
United States	34
Italy	34
Yugoslavia (Serbia)	27
Turkey	14
Russian Federation	13
Sweden dataset	
Brazil	241
Czech Republic	213
Sweden	198
Serbia	189
Italy	101
United States	100
Germany	72
Yugoslavia (Serbia)	68
Russian Federation	46
Yugoslavia (Bosnia-Herzegovina)	40
Switzerland dataset	
Germany	42
United States	27
Czech Republic	23
Brazil	16
Switzerland	14
Italy	13
Russian Federation	4
Israel	3
Bulgaria	2
Mexico	2
China	2

most common headstamps accounted for 1197 cartridges—or almost 40 per cent of the entire sample (Table 5). The most frequently recorded headstamp—'CBC_9 mm LUGER'—was observed on 225 cartridges. This is not necessarily surprising, given that the manufacturer has used this specific headstamp 'for many years, at least four decades'.[18] The uneven distribution of headstamps in the sample indicates that it is possible to distinguish common from rare types of ammunition, and hence to potentially detect new sources of trafficking and diversion when this evolves over time.

3.1.3. Year of manufacture

A total of 864 cartridges—or 28 per cent of the dataset—included marks indicating the cartridges' year of production. Overall, the sample is dominated by old ammunition—the average age of the cartridges in the dataset is 33 years. New ammunition is also present, however, with cartridges manufactured since 2010 representing 24 per cent (or 210 cartridges) of the ammunition with an identifiable date of manufacture. The criminal use of recently produced ammunition illustrates how some cartridges were quickly diverted after production before being used illicitly.

Fig. 6 shows the distribution of these cartridges according to year of production, by five-year periods. The oldest spent cartridge was produced in 1916, but appears to be an outlier. The first peak in production covers the period 1940–44 and coincides with the high levels of production and circulation of ammunition in Europe seen during the Second World War. 39 per cent of the dataset cartridges dated in this period (or 46 pieces) were produced in the former allied powers (Canada, the United Kingdom, and the United States), while 28 per cent were produced in countries belonging to the former Axis coalition (Germany and Finland) or under German occupation at the time (Czechoslovakia and Denmark). Although it was neutral in the conflict, Sweden produced 33 per cent of the cartridges in the dataset that were manufactured during this period.

A second significant period in terms of manufacturing dates is that between 1970 and 1984, which accounted for 247 cartridges (or 29 per cent of the subset of cartridges whose year of production could be determined). Ammunition made during this time includes cartridges produced in the four countries covered in this study. While some of these cartridges were destined for the civilian market—such as the German Geco cases carrying a year code—others were meant for military stocks—such as the Swedish cartridge cases made by Ammunitionsfabriken Karlsborg [32]. Ammunition produced in this period also includes significant proportions of former Warsaw Pact products: 28 cartridges in the dataset were produced in the former Soviet Union between 1971 and 1981, including 16 in the Klimovsk factory in 1978. Another 41 cartridges were produced in the Socialist Federal Republic of Yugoslavia during the period 1980–83.

A third batch of cartridges—representing one-third of the ammunition with an identifiable date of manufacture—shows production dates ranging from the early years of the first decade of the 21st century to 2019, including seven cartridges produced in 2019. These recently made cartridges are primarily produced in Europe and bear headstamps that are mainly consistent with those observed in the civilian market. It is noteworthy that the CIP does not require manufacturers to stamp the year of production on each cartridge—although boxes must carry the year of production—so the year markings seen on these rounds are the initiative of the producers themselves. A total of 136 cartridges were produced from 2015 to 2019. In addition, an ammunition expert[19] determined that a batch of 64 rounds produced in Germany bearing the headstamp 'GECO_9mm LUGER_○' was manufactured since 2015, bringing the total of cartridges produced since that year to 200 cases, or 6 per cent of the full dataset and 23 per cent of the cartridges with a known date of manufacture.

3.2. Trends

This section reviews trends in illicit ammunition by disaggregating the ammunition baseline by crime category and year. It also provides a 'time-to-crime' analysis for a subset of the cartridges whose year of manufacture could be determined, which provides

[18] Author written communication with confidential source, 28 September 2020.

[19] Author correspondence with confidential source, 13 August 2020.

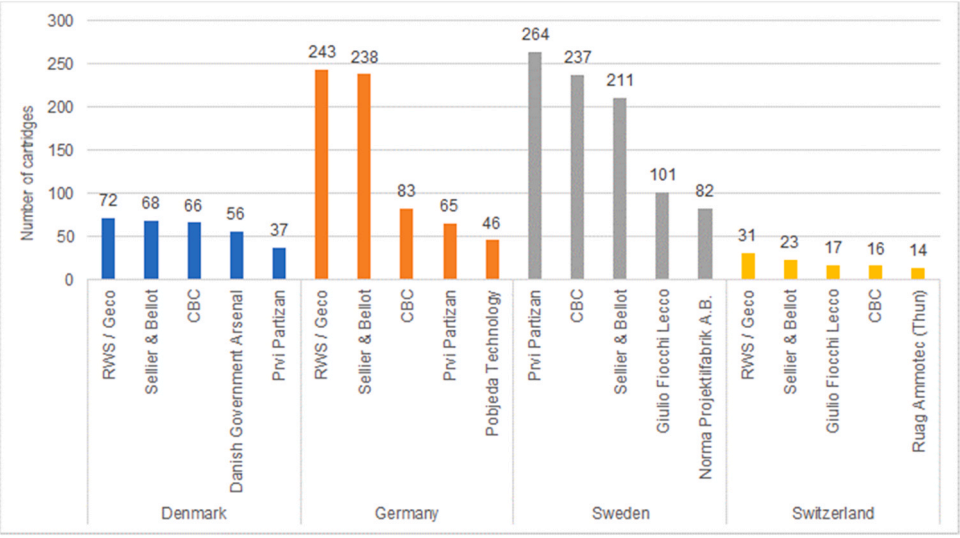

Fig. 5. Top five manufacturers by country.

Table 5
Top 20 headstamps in the full dataset.

Headstamp	Number of cartridges	Manufacturer	Nominal caliber
CBC_9mm LUGER	225	CBC	9 mm Luger
G.F.L._9mm LUGER	91	Giulio Fiocchi Lecco (GFL)	9 mm Luger
CBC_32 AUTO	91	CBC	7,65 mm Browning
S&B_7,65 Br._Ŏ	82	Sellier & Bellot	7,65 mm Browning
PPU_32 AUTO	67	Prvi Partizan	7,65 mm Browning
GECO_9mm LUGER_○	64	RWS/Geco	9 mm Luger
PPU_7,62 TT	63	Prvi Partizan	7,62 × 25 Tokarev
Geco_7.65	58	RWS/Geco	7,65 mm Browning
S&B_7.62×25_Ŏ	55	Sellier & Bellot	7,62 × 25 Tokarev
S&B_9mm LUGER_Ŏ	55	Sellier & Bellot	9 mm Luger
NORMA_7.65 mm	53	Norma Projektilfabrik A.B.	7,65 mm Browning
Geco_9mm Luger	44	RWS/Geco	9 mm Luger
C	39	Cascade Cartridge Inc.	.22 Long Rifle
POBJEDA_9mm PAK	37	Pobjeda Technology	9 mm PA Blanc
UMA_9mm P.A.Knall	36	Sportwaffen Umarex/Titan	9 mm PA Blanc
PPU_9mm LUGER	35	Prvi Partizan	9 mm Luger
CBC_380 AUTO	31	CBC	9 mm Browning court
PPU_380 AUTO	25	Prvi Partizan	9 mm Browning court
S&B_18_9×19	24	Sellier & Bellot	9 mm Luger
Walther_9mm PAK	22	Walther Ammunition	9 mm PA Blanc

some insights into how rapidly ammunition can be diverted for illicit use after it is manufactured.

3.2.1. By crime category

Violent crimes against people, including homicides (35 per cent) and assaults (26 per cent), represent by far the largest category of crime in the full dataset (Table 6). On the other end of the scale, acts against property and drug-related incidents represent only 10 per cent of the sample, while violations of firearms legislation account for 12.5 per cent. Given the weight of violent crimes, it is clear that the distribution by crime category in the dataset is not representative of the overall distribution of these crimes in the four countries under study. Rather, they are representative of those crime categories for which ballistic evidence was recorded: the participating laboratories of Denmark, Germany and Sweden confirmed that all ballistic evidence collected in their respective countries is processed by these countries' national ballistic departments. In Switzerland, each Canton has its own forensic service that collects ballistic evidence and the Zurich Forensic Science Institute (FOR) has and manages the Swiss ballistic database. The fact that the majority of cartridges in the dataset are linked with cases of violent crime is also consistent with other sources.[20]

An important question is whether the profile of ammunition changes according to the type of crime involved. More specifically, do the most prominent calibers for the full dataset—9 mm Luger and 7,65 mm Browning—also dominate all the main crime categories? Fig. 7 shows the top five calibers used in each category of crime. Consistent with the general trend, 9 mm Luger and 7,65 mm Browning dominate the caliber distribution for five of the six categories of crime. While 7,62×25 Tokarev and 9 mm Browning court follow as the third- and fourth-ranked calibers used in both homicides and assaults, other top five calibers are more diverse for other types of offenses. It is noteworthy that 9 mm PA Blanc ranks in the top five for all types of crime except for homicides and drug-related incidents, while 7,62 × 39—the main caliber for AK-pattern rifles—is only commonly used in homicides. This picture is different in

[20] For instance, in 2016 and 2017 '*Denmark and Sweden were among the countries in Europe registering the highest proportions of seized arms linked to violent crime*' [33].

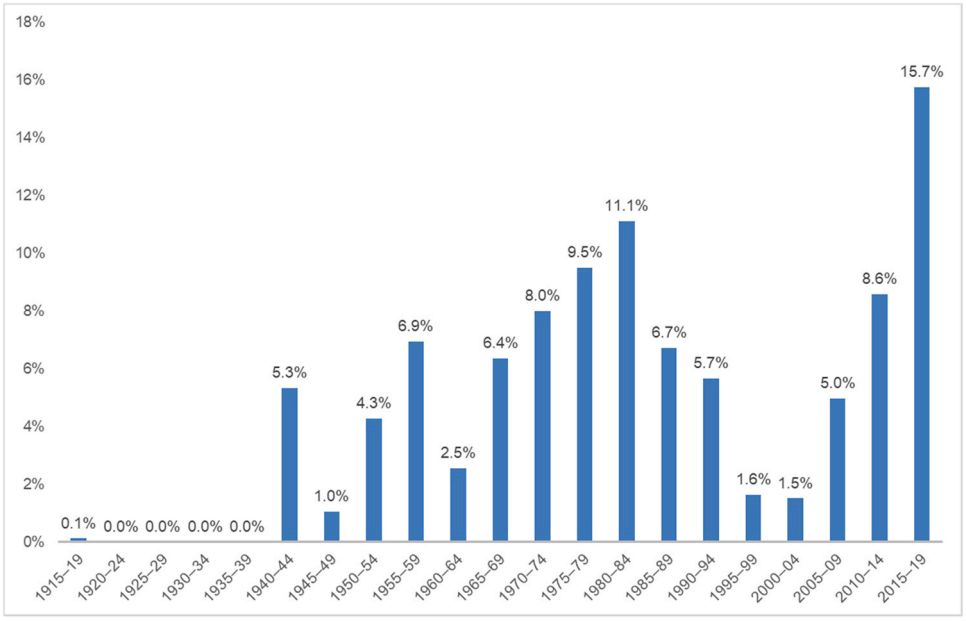

Fig. 6. Distribution of cartridges by year of manufacture (per cent, n = 864), 1915–2019.

Table 6
Distribution of cartridges by crime category (number of cartridges).

Crime category	Denmark	Germany	Sweden	Switzerland	Total
Homicides	44	402	608	44	1098
Assaults	292	93	425	2	812
Other acts	226	29	202	67	524
Violation of firearms legislation	38	163	187	4	392
Acts against property	3	219	35	36	293
Drug-related incidents	0	9	2	0	11
Total	**603**	**915**	**1459**	**153**	**3130**

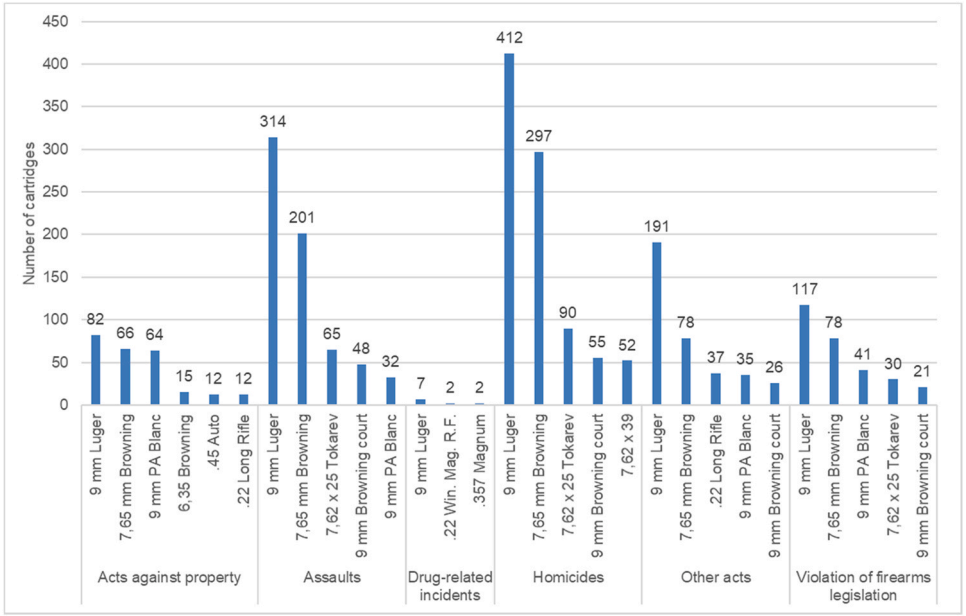

Fig. 7. Top five calibers by crime category for the full dataset.

Sweden, however, where 7,62 × 25 Tokarev, 7,62 × 39, and 9 mm Browning court are the calibers most commonly used in homicides and assaults.

The distribution of top manufacturers is not consistent across the main crime categories (Fig. 8). Sellier & Bellot features in the top two producers of cartridges used for homicides in all four country datasets. Sellier & Bellot and RWS/Geco cartridges are most commonly used in assaults and homicides in Germany and Switzerland, and account for more than half of the cartridges retrieved in such cases. In Sweden Prvi Partizan and CBC are the top two producers, with

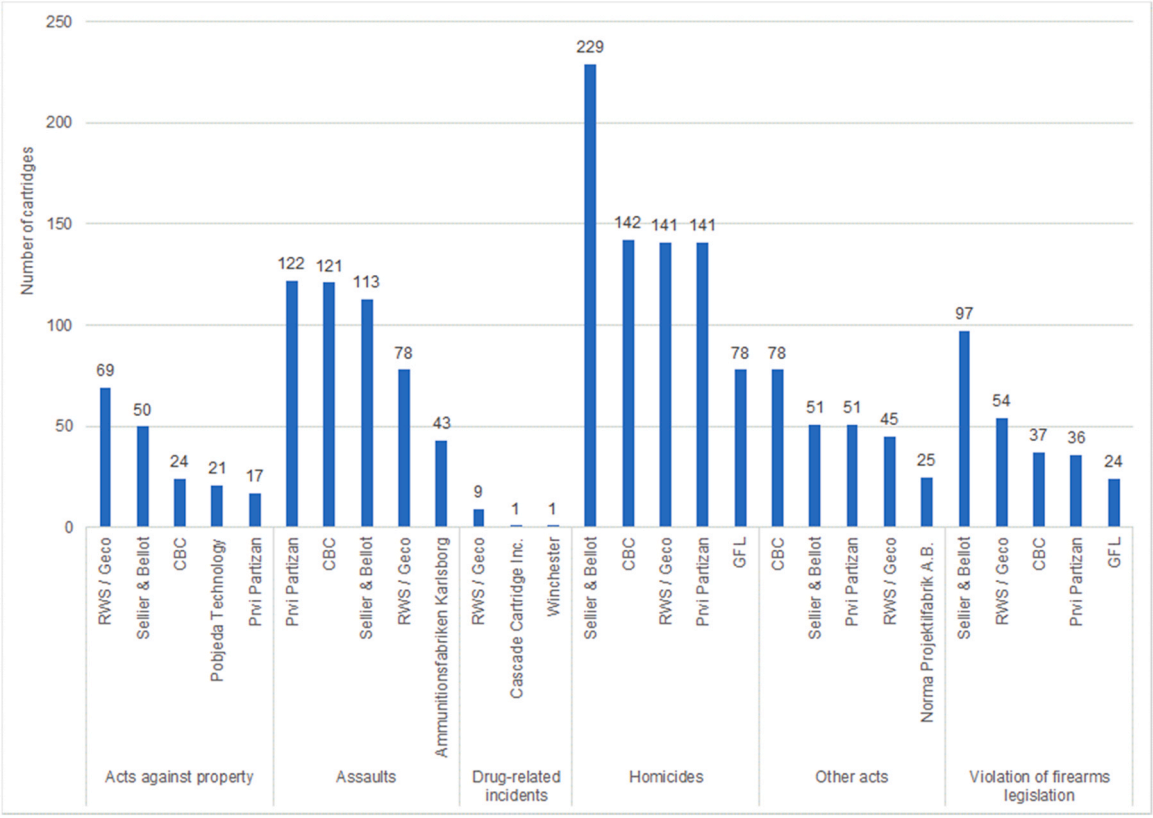

Fig. 8. Top five manufacturers depending on the crime category for the full dataset.

Sellier & Bellot third. In Denmark locally manufactured cartridges (Danish Government Arsenal) are also widely used in violent crimes.

Also of note is the high concentration of recently produced ammunition in homicide cases. Indeed, three-quarters of the cartridges produced between 2015 and 2019 were linked to homicide cases.

Overall, while there are some commonalities in the profile of ammunition used for perpetrating the various categories of crime, there are also some differences. This suggests that more in-depth monitoring and analysis of ammunition used by type of crime can shed light on crime-specific patterns of use and sources of acquisition.

3.2.2. By year

The total number of incidents and cartridges recorded per year increased slightly between 2015 and 2019 (Fig. 9). The picture varies at the country level, however. While the annual number of incidents

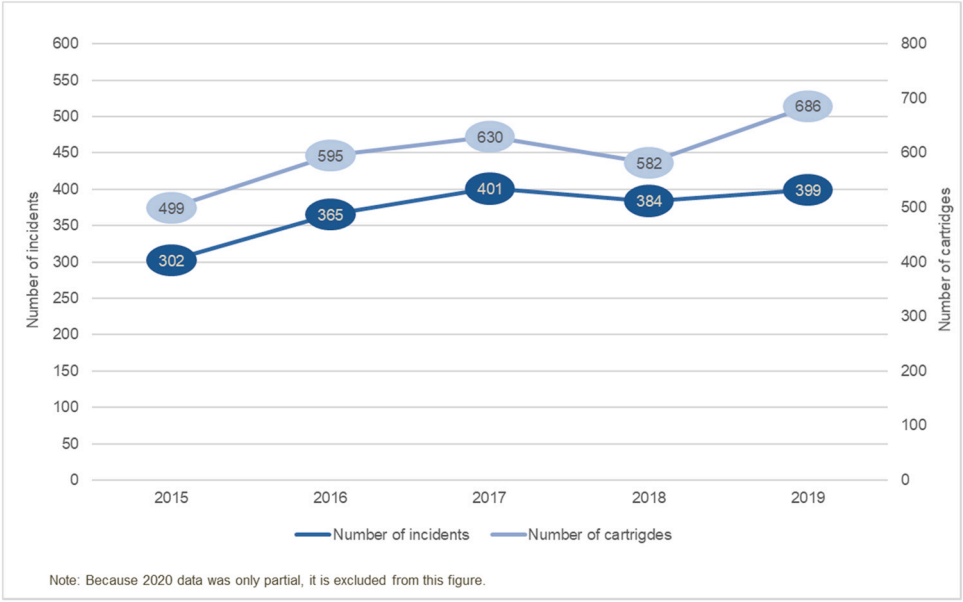

Fig. 9. Number of incidents (n = 1851) and cartridges (n = 2992) for the full dataset, 2015–19.

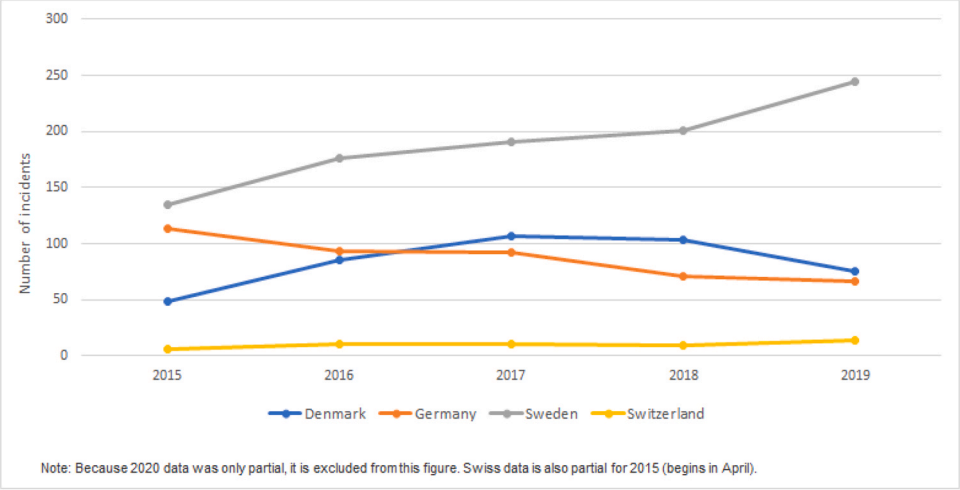

Fig. 10. Number of incidents by country (n = 1851), 2015–19.

Table 7
Top five calibers per year of incident, 2015–19.

Year	1st	2nd	3rd	4th	5th
2015	9 mm Luger	7,65 mm Browning	7,62 × 25 Tokarev	6,35 Browning	9 mm PA Blanc
2016	9 mm Luger	7,65 mm Browning	9 mm PA Blanc	7,62 × 25 Tokarev	9 mm Browning court
2017	9 mm Luger	7,65 mm Browning	7,62 × 25 Tokarev	9 mm PA Blanc	7,62 × 39
2018	9 mm Luger	7,65 mm Browning	9 mm Browning court	7,62 × 25 Tokarev	9 mm PA Blanc
2019	9 mm Luger	7,65 mm Browning	7,62 × 25 Tokarev	9 mm PA Blanc	9 mm Browning court

Table 8
Top five calibers used in homicides in Sweden per year of incident, 2015–19.

Year	1st	2nd	3rd	4th	5th
2015	9 mm Luger	7,65 mm Browning	.40 S&W	.45 Auto	n/a
2016	9 mm Luger	7,65 mm Browning	9 mm Makarov	7,62×39	7,62 × 25 Tokarev
2017	9 mm Luger	7,62 × 25 Tokarev	7,65 mm Browning	7,62×39	.22 Long Rifle
2018	9 mm Luger	7,65 mm Browning	7,62 × 25 Tokarev	7,62×39	9 mm Makarov
2019	9 mm Luger	7,65 mm Browning	7,62 × 25 Tokarev	7,62×39	9 mm Browning court

decreased in Denmark and Germany between 2018 and 2019, it increased in Sweden and Switzerland (Fig. 10). The increase is particularly significant in Sweden, which experienced a 41 per cent increase in firearm-related homicides and a 49 per cent increase in the number of violations of firearms legislation during this period.

Caliber distribution remains consistent from year to year, with 9 mm Luger and 7,65 mm Browning ranking as the top calibers for all the years under review (Table 7). 7,62 × 25 Tokarev, 9 mm PA Blanc, and 9 mm Browning court[21] are the recurring calibers featuring in third, fourth, and fifth places, although in different order from year to year. 7,62 × 25 Tokarev is common in all four country datasets, but is mostly prominent in the Swedish dataset, where it accounts for more than 75 per cent of all cartridges of this caliber. 7,62 × 39 caliber cartridges only appear in the top five in 2017, which is also due to its prevalence in the Swedish dataset. It is noteworthy that 7,62 × 39 caliber cartridges feature in the top five calibers used in homicides in Sweden from 2016 to 2019 (Table 8), a period during which firearm-related cases recorded in the country increased substantially.

Five manufacturers—Sellier & Bellot, RWS/Geco, CBC, Prvi Partizan, and GFL—frequently constitute the list of top five producers irrespective of the year of the incident. The only exceptions are 2017 and 2020, when Norma and Cascade replaced GFL and CBC, respectively.

Overall, variations over time of the general profile of the documented ammunition were fairly minimal for the full dataset. It should be noted, however, that the five-year study period is limited, and that the analysis of data covering a longer period and disaggregated by the month of the incident—rather than the year— has the potential to uncover more-revealing temporal patterns and variations. The emergence of 7,62 × 39 as a common caliber in Sweden in recent years is a case in point.

3.2.3. 'Time-to-crime' analysis

The US Bureau of Alcohol, Tobacco, Firearms and Explosives defines time-to-crime as 'the period of time (measured in days) between the first retail sale of a firearm and a law enforcement recovery of that firearm during a use, or suspected use, in a crime' [35]. US analysts consider a time-to-crime of less than three-to-four years as a potential indicator of recent trafficking worthy of further investigation, given the short time span elapsed between legal sale and diversion or illicit use [36].

While time-to-crime analysis usually focuses on firearms, the same principle can be used with some of the ammunition reviewed in this dataset, but working from the cartridge's date of manufacture. For the 28 per cent of cartridges in the dataset that bore a date of production, it is indeed possible to calculate the time that separates

[21] It is interesting to note that Danish and Swedish police recently seized Ekol and Zoraki pistols that were 'professionally converted to appear as Glock 25'—a firearm whose caliber is 9 mm Browning court—including 55 pistols in 2018 [34].

Table 9
Average time-to-crime by country when cartridge date of manufacture is known (in years; n = 864).

Country case study	Average time-to-crime
Denmark	40
Germany	22
Sweden	35
Switzerland	31
Full dataset	**33**

ammunition may be easier to find in the country. Cases of short time-to-crime ammunition can be valuable for intelligence–led policing as they demonstrate that criminals gained access to ammunition produced recently. They should be investigated thoroughly to identify the source and point of diversion.

Average time-to-crime also varies greatly when disaggregated by caliber and type of crime. With respect to the main calibers, 9 mm Luger and 7,62 × 39 cartridges have time-to-crime values that are close to the 33 year average, while 7,65 Browning's measure is below

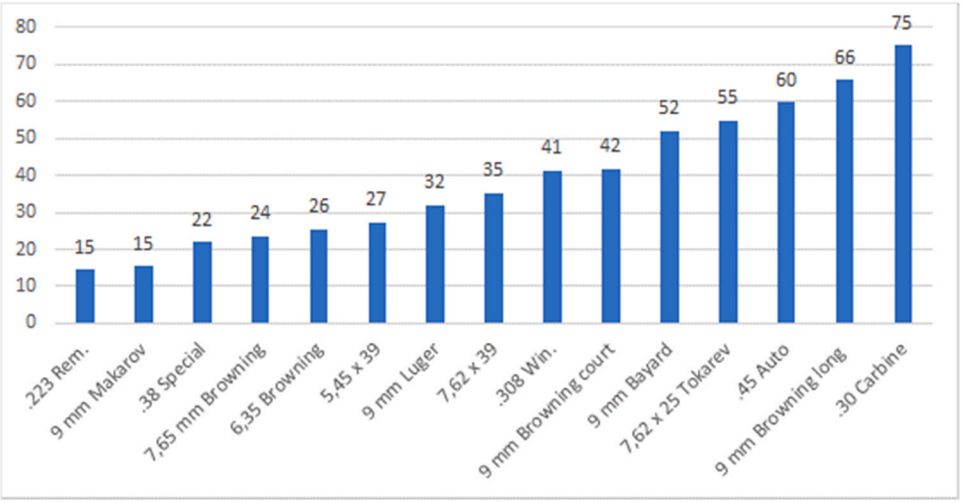

Fig. 11. Average time-to-crime in years, by caliber (n = 864).

the year of manufacture from the year that the cartridge was processed in the ballistic laboratories—bearing in mind that there can be a small time gap between the time of seizure of the cartridge and its integration into the ballistic system.[22]

The average time-to-crime for the dataset is 33 years, which illustrates how criminals do not hesitate to use old or even very old cartridges (Table 9). Germany stands out as the country with the shortest time-to-crime average at 22 years, in spite of the presence of a cartridge manufactured in 1916 in its dataset.

Overall, cartridges with longer time-to-crime periods tend to come from a wide range of manufacturers—including, but not limited to, military surplus cartridges produced at the Igman Zavod Konjic and Lugansk State Ammunition factories.

In contrast, cartridges with a shorter time-to-crime tend to be those intended for the civilian market. Among them, Sellier & Bellot is particularly common. The average time-to-crime for all Sellier & Bellot cartridges carrying a year-of-manufacture stamp (212 units) is just four years. Sellier & Bellot cartridges also account for 95 per cent of the ammunition featuring a time-to-crime of one year. The remaining 5 per cent are distributed between Makina ve Kimya Endustrisi Kurumu (3 per cent) and Speer (2 per cent). In total, 27 cartridges were produced in the same year as that of the incident in which they were used, and 66 were manufactured in the year preceding the incident.

Such statistics suggest a shift in the illicit market for ammunition, with illicit users seemingly turning to intra-European sources in recent years—presumably as a consequence of the relative depletion of old stocks in Eastern Europe. Germany's position as one of the main manufacturers of ammunition found in the dataset may explain its smaller time-to-crime value, because recently made

[22] The participating laboratories explained that depending on the urgency of the case, it can take between a few hours to two months for a piece of ballistic evidence to be processed after its recovery.

the average at 22, and 7,62 × 25 Tokarev is well above it at 55 (Fig. 11). With respect to crime categories, time-to-crime values are above average for assaults, other acts, and acts against property, and below average for homicides and violations of firearms legislation (Fig. 12).

Overall, the significant variations in time-to-crime values found across countries, calibers, manufacturers, and categories of crime suggest that more in-depth monitoring and analysis of this variable has the potential to reveal important patterns of ammunition diversion. This analysis is only possible with ammunition whose date of manufacture is known, which highlights the utility of year of production markings on ammunition headstamps.

3.3. Other trends and observations

The ammunition experts who were involved in the research made a series of observations during the research process that went beyond headstamp analysis and are relevant to the work of forensic examiners and firearm investigators. This section summarizes noteworthy patterns they could identify as they relate to inkjet markings on surplus ammunition, the criminal use of blank and non-factory ammunition, and elliptical firing pin marks.

3.3.1. Surplus ammunition and inkjet markings

Since the beginning of the second decade of the 21st century ammunition retailers in some countries—and notably those that are members of the CIP[23]—use inkjet printers to print additional

[23] According to CIP regulations, surplus ammunition must be tested like normal cartridges and be clearly identifiable as such, and 'all cartridges … must bear … manufacturer's mark or a mark of origin … to the base or the casing [and] the caliber in compliance with C.I.P. nomenclature. If it is impossible for technical reasons to show the caliber on the base, it may be marked in indelible fashion on the body of the casing' [37].

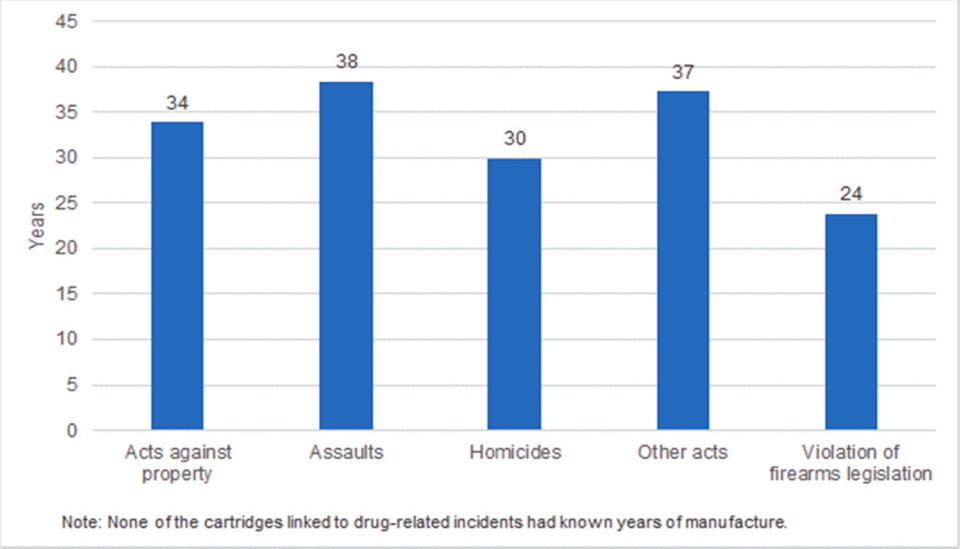

Fig. 12. Average time-to-crime in years, by crime category.

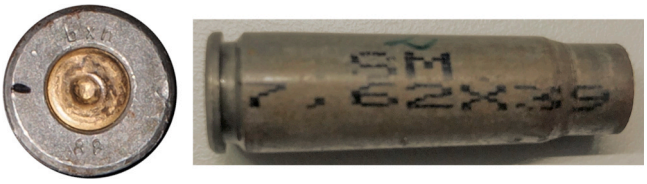

Fig. 13. 7,62 × 39 cartridge case with a 'bxn_88′ headstamp and an 'SM 7,62×39′ inkjet marking on the case.

markings on the body of the cartridge cases that originate from surplus stocks and are sold on the civilian market.[24] These inkjet markings typically include an alphabetical code that identifies the retailer and the ammunition's caliber. While it is often impossible to determine the recent chain of custody of surplus ammunition produced decades ago, these additional markings can help to provide additional and more recent information on the last legal transaction involving the ammunition in question.

While surplus ammunition features in the datasets of all four case study countries, Germany is the only member of the CIP. Additional information on inkjet markings visible on the bodies of typical surplus cartridges included in the German dataset revealed a 2015 case of 'violation of firearms legislation' that involved three 7,62 × 39 cartridges cases with a 'bxn_88' headstamp and an 'SM 7,62×39' inkjet marking on the case (see Fig. 13). 'SM' identifies the Chemnitzer Sportwaffen- und Munitionsfabrik GmbH company as the entity that sold this surplus ammunition.[25] However, it was not possible to determine when and where this ammunition was tested before being sold on the civilian market.[26] Integrating the recording of inkjet markings into future ammunition studies and protocols nevertheless has the potential to shed new light on the diversion of surplus ammunition.[27]

Fig. 14. 9 mm Browning court Starline cartridge case with a Magtech primer.

3.3.2. Criminal use of 'non-factory' ammunition

Two series of headstamps included in the dataset point to the presence of non-factory ammunition, defined here as ammunition assembled from new cartridge cases by using reloading equipment. Headstamps indicating production by Starline—a US-based company that only produces unprimed cartridge cases—were observed in the datasets of all four case study countries. Turning these cartridge cases into live ammunition requires loading them with a primer and powder, and crimping a bullet. All in all, 24 criminal cases in the dataset involved 32 Starline rounds produced in nine handgun calibers, notably 9 mm Browning court (15 items/12 criminal cases) and 7,62 × 25 Tokarev (4 items/2 criminal cases); 31 (1/3) of the Starline cartridges were used in homicides. In two separate cases in Sweden the Starline cartridge cases had the same Magtech primers (with a double V logo or X-shaped), possibly suggesting a common origin (see Fig. 14). Similarly, the dataset includes several cartridges marked as produced by Hornady—a company that produces both finished ammunition and unprimed cases.[28] Entries for four Hornady cartridges were integrated into the Swedish ballistic database in 2018, all of 9 mm Browning court caliber,[29] with the same headstamp and singular crossing lines on the primers that appear to be handmade[30] (see Fig. 15).

[24] Common military surplus calibers sold on the civilian market include 5,45 × 39, 7,62 × 25 Tokarev, 7,62 × 39,.308 Win., and 7,62 × 54 R.

[25] In addition to SM, STV Group and Zeleny Sport, both in the Czech Republic, are important European retailers of surplus ammunition.

[26] One batch typically contains 500,000 rounds of consistent ammunition. In CIP countries the national proof house reports on the batches it tests and certifies to the CIP Secretariat in Brussels, which then publishes this information online. In practice, however, national proof houses do not all report this information systematically (author written communication with confidential source, 26 August 2020).

[27] Ammunition featuring such markings has also been recorded outside of CIP countries and as far afield as Senegal [38].

[28] See Hornady Reloading [39].

[29] 9 mm Browning court is the CIP nomenclature for.380 AUTO.

[30] These markings are not consistent with those of shell holders or any other typical tool used in this reloading process.

Fig. 15. Hornady cartridge case of 9 mm Browning court caliber with singular crossing lines on the primers that appear to be handmade.

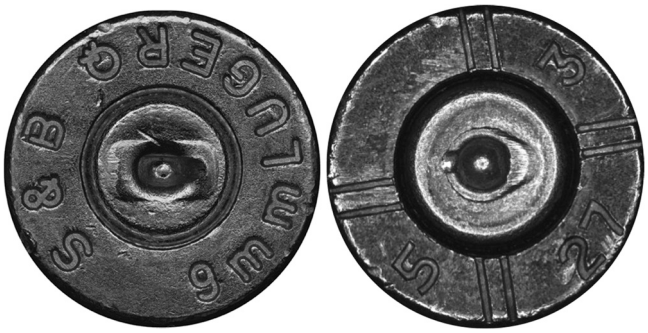

Fig. 16. Examples of a rectangular (left) and a teardrop shear mark (right).

The imagery available to the researchers did not suggest that any of the cartridges in the dataset were previously fired rounds that were subsequently reloaded. This may reflect a lack of criminal use of reloaded ammunition, but could also be the consequence of forensic examiners' decisions to discard cartridges carrying 'contaminated' ballistic traces from previous discharges.[31]

3.3.3. Criminal use of blank ammunition

In total, 205 cartridge cases in the dataset bore markings suggesting that they were blank ammunition, including 192 cases of 9 mm PA Blanc, 8 cases of 9 mm R Blanc (for revolvers), and 5 cases of 8 mm Blanc, while 9 mm PA Blanc ammunition is present in the top ten of all four countries. This is of interest, given Europe-wide concerns related to the criminal use of alarm handguns, because both blank-firing weapons and ammunition can be modified to fire lethal projectiles [40,41]. Even without any modification, blank pistols and revolvers can be used for criminal purposes. In response to this threat, the European Commission adopted technical specifications for alarm and signal weapons in January 2019, as it observed that 'some devices designed for alarm, signaling or life-saving purposes that are currently available on the market can be easily converted to firearms using ordinary tools' [42]. Although headstamp images cannot on their own be used to determine if a fired blank cartridge was modified to fire a projectile, three 9 mm PA Blanc rounds in the German dataset were reported by the laboratory as modified. Recording the modifications performed on blank cartridges has the potential to assist efforts to monitor and counter the criminal use of converted firearms, especially if the techniques and tools used for ammunition seized in separate cases point towards a single workshop.

3.3.4. Rectangular and teardrop firing pin impressions/shear marks

Models of Glock pistols until the Gen 4, as well as Smith & Wesson's Sigma series pistols, the Springfield Armory XDS9 pistol, and Turkish-made Sarsilmaz SAR 9 pistols produce very specific ballistic marks—more or less rectangular—called shear marks that are visible on the primer of a spent cartridge (see Fig. 16). These traces are due to the distinctive elliptical firing pin used in these pistols, which moves through a rectangular firing pin hole. Seven per cent of the cartridges reviewed in the whole dataset carry such marks, with the highest proportion seen in Sweden (9 per cent of the Swedish dataset) and the lowest in Denmark and Switzerland (5 per cent of each dataset). The calibers concerned are mainly 9 mm Luger, together with a few rounds of 10 mm Auto, .40 S&W, and .45 Auto.[32] The brand of ammunition was predominantly CBC and Sellier & Bellot, while the main associated types of crimes were homicides and assaults, except in Switzerland, where the ammunition was typically used in 'other acts'. In 2014 Glock introduced a new manufacturing process for Gen 4 Models 42 and 43 and, since 2017, for the Gen 5 series, and so these marks are no longer visible on cartridges fired by these more recent models [43]. The new teardrop shaped firing mark of these newer models resembles a circular shear mark (see Fig. 16), which has been observed very marginally in this study. It should be noted that the Smith & Wesson M&P (Military and Police) pistol also leaves this type of firing pin impression [44]. This example illustrates the value of observing headstamp imagery as visible toolmarks such as those left by the firing pin can help identify the specific models of firearms used in a shooting—including firearms produced only recently and whose point of diversion might be more easily investigated. Compiling this information can help establish links between cases that could subsequently be confirmed through toolmark examination (including individual characteristics).

4. Conclusion

This pilot study has showed the feasibility of extracting imagery of cartridge cases and contextual data from ballistic systems to fairly quickly analyse ammunition used in crime. This information makes it possible to generate a baseline of the main types of ammunition used in several important categories of crime. Most of the ammunition (61 per cent) was recovered in the context of violent types of crime—homicides and assaults—for which pistol calibers were the most prominent. 610 unique headstamps were recorded, but only a small proportion of these varieties of ammunition were used particularly frequently. All four country datasets included both foreign-made ammunition as well as cartridges produced domestically. The year of manufacture could be identified for 28 per cent of the cartridges, and at least 27 pieces of ammunition were produced in the year that the criminal incident took place. The dataset also revealed additional trends such as the criminal use of blank ammunition across case studies, as well as the relatively new prevalence of the 7,62 × 39 caliber in Sweden.

In addition to shedding new light on types of ammunition used in crime in the European context, monitoring illicit ammunition can in the longer run help detect new sources of supply used by criminals and can therefore potentially support police investigations. Headstamps and inkjet markings data that specify the year of manufacture or the last retailer or purchase can reveal recently diverted varieties of ammunition whose supply chains require rapid

[31] Participating laboratories explained that they see limited numbers of reloaded rounds, which tend to originate from shooting clubs. When ballistics examiners have the choice between reloaded and new ammunition, they tend to only select the new ammunition for analysis given the possibility that reloaded rounds feature traces from previous shootings. If only reloaded ammunition is found at the crime scene, it will be processed in the ballistics system, however.

[32] These calibers are all possible Glock pistol calibers, while only some are possible Smith & Wesson's Sigma series pistol calibers (9 mm Luger and 0.40 S&W), Springfield Armory's XDS9 pistol caliber (9 mm Luger), or Sarsilmaz SAR 9 pistol caliber (9 mm Luger).

investigation. Detecting identical varieties of ammunition that were used in different incidents or with different firearms may also suggest new linkages between cases. Finally, undertaking in-depth geospatial analysis of the relationship between crime patterns and the type of cartridges used—while beyond the scope of the data accessed for this study—is also possible and can in turn help determine the possible points of entry used by traffickers, as well as serve as a basis for assessing whether law enforcement operations have successfully dismantled supply networks. Some of the participating laboratories noted that they are already expected to provide investigators with analysis on the type of ammunition used and how common it is. Integrating ammunition headstamp analysis into ballistic systems, or other relevant databases,[33] would therefore help forensic experts save time and centralize this information so that it can support the production of real-time assessments of the ammunition in illicit use and help identify possible linkages between cases.

Ballistic laboratories' cartridge selection protocols need to be adjusted, however, to ensure the greater representativeness of the ammunition that they include in their datasets. Maintaining records of the caliber, manufacturer, and year of production of the cartridges used in both open and solved cases seems crucial in this regard. Cartridges that are entered in the systems should also be selected not just on the basis of their ballistic traces, but also with the aim to capture the variety of makes and years of production of the ammunition that is retrieved at crime scenes. Including reloaded cartridges more systematically—in spite of their contaminated marks—would provide important insights on the extent of criminal use of such ammunition, while also integrating unspent ammunition found at crime scenes would further increase the scope of the datasets. Finally, recording the presence of additional markings on the body of cartridge and shotshell cases, and noting whether blank ammunition was modified to fire projectiles would help produce valuable intelligence for countering the diversion of ammunition and trafficking in converted firearms.

In the future, headstamp analysis and ammunition monitoring could be more systematically integrated into the procedures of ballistic laboratories in various ways. As is already the case in some countries, forensic institutions can record headstamps and inkjet markings data as part of their protocols for examining ballistic evidence and design specific datasets for this purpose. Given the degree of sophistication of ballistic systems, it also appears feasible to more systematically integrate the collection of ammunition data (headstamps and inkjet markings, whether ammunition was modified, etc) into these platforms—either manually by adding relevant fields and 'drop-down menus,' or, possibly, by using automatic character-recognition technologies. Whichever strategy is used, reasonable investments should yield valuable intelligence and analysis for the purposes of both policy-making and policing, and can help to reduce the current knowledge gap regarding the criminal use of and trafficking in ammunition.

CRediT authorship contribution statement

André Desmarais: Conceptualization, Methodology, Validation, Investigation, Writing - Original Draft, Writing – review & editing; **Anne-Séverine Fabre:** Methodology, Formal analysis, Writing – original draft, Writing - Review & Editing, Visualization; **Benjamin Jongleux:** Conceptualization, Methodology, Investigation; **Glenn Lawrence:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing; **Denis Werner:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing; **Nicolas Florquin:** Conceptualization, Methodology, Validation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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Declarations of interest

none.

References

[1] INTERPOL (International Criminal Police Organization), Firearms operations and events,〈〉https://www.interpol.int/Crimes/Firearms-trafficking/Firearms-operations-and-events, n.d. (accessed 20 December 2020).
[2] UNODC (United Nations Office on Drugs and Crime), Global Study on Firearms Trafficking 2020, 2020, p.128. 〈https://www.unodc.org/unodc/en/firearms-protocol/firearms-study.html〉.
[3] Connecticut Historical Society, Gilman Family Papers: A Guide to the Gilman Family Papers at the Connecticut Historical Society, n.d. 〈https://chs.org/finding_aides/finding_aids/gilmf1787_pdf.pdf〉.
[4] N. Florquin, J. Leff, Across Conflict Zones: Ammunition Profiling, in: Small Arms Survey (Ed.), Small Arms Survey 2014: Women and Guns, Cambridge University Press, 2014, p. 180 https://smallarmssurvey.org/sites/default/files/resources/Small-Arms-Survey-2014-Chapter-6-EN.pdf.
[5] G. Burrard, The Identification of Firearms and Forensics Ballistics, Herbert Jenkins,, London, 1934, pp. 194–195.
[6] FBI (Federal Bureau of Investigation) Focus. FBI Law Enforc. Bull. 58 12 1989 25. 〈https://leb.fbi.gov/file-repository/archives/december-1989.pdf/view〉.
[7] S. Jorion, P. Regenstreif, Culots de munitions: atlas, Tomes I et II, Cépaduès-Editions, Toulouse, 1994.
[8] H.A. Erlmeier, J.H. Brandt, Manual of pistol and revolver cartridges – Volume 1, Journal Verlag Schwend GmbH, Schwäbisch Hall, 1980.
[9] H.A. Erlmeier J.H. Brandt Manual of pistol and revolver cartridges – 1980 Journal Verlag Schwend GmbH, Schwäbisch Hall.
[10] J.H. Brandt, A. Müller, Manual of pistol and revolver cartridges – Volume 3, Journal Verlag Schwend GmbH, Schwäbisch Hall, 1980.
[11] M. am Rhyn, Données sur le culot de la douille des cartouches suisses, Luzern and Steffisburg, 1985.
[12] H.P. White, B.D. Munhall, Cartridge Headstamp Guide, H.P. White laboratory,, Maryland, 1963.
[13] S. Jorion, P. Regenstreif, J. Avon, Cartouches: Atlas d'identification des marques de culot des munitions d'armes légères, Paris,, Crépin-Leblond, 1978.
[14] C. Conklin, Military cartridge headstamps collector's guide, Heritage Books,, Westminster, 2007.
[15] AFTE (Association of Firearm and Tool Mark Examiners), AFTE Headstamp Guide. 〈https://afte.org/resources/headstamp-guide〉, 2020 (accessed 21 November 2020).
[16] AECC (Asociación Española de Coleccionistas de Cartuchos). Municion.org. Website. 〈http://old.municion.org〉, n.d. (accessed 18 December 2020).
[17] IAA (International Ammunition Association). Headstamp Codes. 〈http://www.cartridgecollectors.org/?page=headstampcodes〉, n.d. (accessed 21 November 2020).
[18] CartWinPro, Database, n.d. 〈https://www.cartwinpro.com/index_us.htm〉.
[19] A. Malaret Baldo, M. Martinez Miralles, UNIDIR - Handbook to Profile Small Arms Ammunition in Armed Violence Settings. 〈https://unidir.org/publication/handbook-profile-small-arms-ammunition-armed-violence-settings〉, 2020, p.110.
[20] E.F. Law, K.B. Morris, C.M. Jelsema, Determining the number of test fires needed to represent the variability present within 9mm Luger firearms, Forensic Sci. Int. 276 (2017) 126–133.

[33] Such as laboratory information management systems, or LIMS, for instance.

[21] E.F. Law, K.B. Morris, C.M. Jelsema, Determining the number of test fires needed to represent the variability present within firearms of various calibers, Forensic Sci. Int. 290 (2018) 56–61.
[22] UNODC, International Classification of Crimes for Statistical Purposes (ICCS), 2015. ⟨https://www.unodc.org/documents/data-and-analysis/statistics/crime/ICCS/ICCS_English_2016_web.pdf⟩.
[23] C. Sautier, S. Christen, F. Chidiac, Sharing ballistic data across Europe: a prototype network between France and Switzerland using Evofinder®, Forensic Sci. Int.: Synerg. 3 (2021) 100148.
[24] CIP (Commission internationale permanente pour l'épreuve des armes à feu portatives), TDCC – Tables of Dimensions of Cartridges and Chambers. ⟨https://cip-bobp.org/en/tdcc⟩, n.d. (accessed 21 November 2020).
[25] B. Heard, Handbook of Firearms and Ballistics: Examining and Interpreting Forensic Evidence, second ed., Wiley-Blackwell,, Hoboken, 2008, pp. 97–98.
[26] H.-C. Lee, H.-H. Meng, Forensic Examination of Fired Bullets and Cartridge Cases of 9 mm Luger Imitation Ammunition, Forensic Sci. J. 10 (1) (2011) 11–18.
[27] Fortune Business Insights, Defense Platforms/Small Calibre Ammunition Market, Report No. FBI102795 (2020). ⟨https://www.fortunebusinessinsights.com/small-caliber-ammunition-market-102795⟩.
[28] A.A. Braga, P.J. Cook, The association of firearm caliber with likelihood of death from gunshot injury in criminal assaults, J. Am. Med. Assoc. Netw. Open 1 (3) (2018) 6, https://doi.org/10.1001/jamanetworkopen.2018.0833
[29] The News, Kalashnikov Culture Bows out to the 9mm Era. ⟨https://www.thenews.com.pk/archive/print/396856-kalashnikov-culture-bows-out-to-the-9mm-era⟩, 2012 (accessed 18 November 2020).
[30] M. Schroeder, On the record: illicit weapons in the United States, in: Small Arms Survey (Ed.), Small Arms Survey 2014: Women and Guns, Cambridge University Press, Cambridge, 2014, p. 267 https://www.smallarmssurvey.org/sites/default/files/resources/Small-Arms-Survey-2014-Chapter-8-EN.pdf.
[31] N. Florquin, E. Hainard, B. Jongleux, Trade Update 2020: An Eye on Ammunition Transfers to Africa, Small Arms Survey, Geneva, 2020, p.20. ⟨https://www.smallarmssurvey.org/sites/default/files/resources/SAS-Trade-Update-2020.pdf⟩.
[32] AFERHM (Association Française d'études et de recherches historiques sur les munitions), Codes Allemands et Autrichiens, 1980, p.49.
[33] UNODC, Global Study on Firearms Trafficking, 2020, p.35. ⟨https://www.unodc.org/unodc/en/firearms-protocol/firearms-study.html⟩.
[34] Europol (European Union Agency for Law Enforcement Cooperation), Converted Zoraki 917 and Ekol Gediz Gas/alarm Pistols, Bulletin: Europol Newsletter of Firearms and Explosives Trafficking. Issue 9 (2019), p.3.
[35] ATF (Bureau of Alcohol, Tobacco, Firearms and Explosives), 2011. ATF Firearms Tracing Guide: Tracing Firearms to Reduce Violent Crime. ATF Publication 3312. 13, p.6. ⟨https://www.atf.gov/file/58631/download⟩.
[36] C. Koper, Crime Gun Risk Factors: Buyer, Seller, Firearm, and Transaction Characteristics Associated with Gun Trafficking and Criminal Gun Use, National Institute of Justice,, 2007, p. 10 ⟨https://nij.ojp.gov/library/publications/crime-gun-risk-factors-buyer-seller-firearm-and-transaction-characteristics⟩.
[37] CIP (Commission internationale permanente pour l'épreuve des armes à feu portatives), 2014. 3. Testing of ammunition: 3.1. Testing of Commercial Ammunition [XV-7]. ⟨https://www.cip-bobp.org/homologation/uploads/ciptexts/d-3–1-2014-en-2.pdf⟩.
[38] C. Sidya, Sénégal: mystère autour de la saisie de 3.900 munitions de guerre destinées à la Mauritanie. Le 360. ⟨https://m.le360.ma/afrique/mauritanie-senegal/societe/2019/11/03/28440-senegal-mystere-autour-de-la-saisie-de-3900-munitions-de-guerre-destinees-la⟩, 2019 (accessed 21 November 2020).
[39] Hornady Reloading, Cartridge Cases: The of Foundation of Hornady® Ammunition, ⟨https://www.hornady.com/reloading/cartridge-cases#!/⟩, n.d. (accessed on 19 November 2020).
[40] N. Florquin, B. King, From Legal to Lethal: Converted Firearms in Europe, Small Arms Survey,, Geneva, 2018, pp. 44–45 https://smallarmssurvey.org/resource/legal-lethal-converted-firearms-europe.
[41] B. Jongleux, N. Florquin, 2020. Monitoring the Response to Converted Firearms in Europe. EU Non-Proliferation and Disarmament Consortium. No. 70. ⟨https://www.nonproliferation.eu/monitoring-the-response-to-converted-firearms-in-europe/⟩.
[42] EU (European Union), Implementing Directive (EU) 2019/69 of 16 January 2019 laying down technical specifications for alarm and signal weapons under Council Directive 91/477/EEC on control of the acquisition and possession of weapons.
[43] A. Boyle, To Glock or not to Glock? Firing Pin Shapes: 2019 Update, Ultra. ⟨https://www.ultra-forensictechnology.com/en/news/blog/to-glock-or-not-to-glock-firing-pin-shapes-2019-update/⟩, 2019 (accessed on 19 November 2020).
[44] C. Monturo, Forensic Firearm Examination, Academic Press, London, 2019.
[45] N. Florquin, Gun Violence: Insights from International Research, Global Crime (2021) 13–14 https://doi.org/10.1080/17440572.2021.1997741.