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An Experience Report Regarding the Performance of the IBIS™ Correlator

ABSTRACT: The majority of published experimental evaluations of the performance of the IBIS™ system are based on very specific conditions, mainly considering IBIS™ as a tool to create a "ballistic database." No recent reports were found covering the performance of the IBIS™ system to search an open case file of realistic structure. In this paper, the performance of the IBIS™ correlator will be evaluated, based on four different data sources that predominantly concern the operation of the central collection of evidence ammunition of the Federal Criminal Police Office (BKA), Germany. The results allow a conclusion on the success and error rates to be expected of the IBIS™ correlator in a realistic OCFDB ("open case file database") environment, given certain conditions. It was found that success rates of 75–95% for cartridge case comparisons and 50–75% for bullet comparisons can be achieved in practice. Recommendations for a most efficient way to operate the IBIS™ electronic comparison system will be presented based on the results of the evaluations. The terms and definitions in this report completely correspond with the definitions in an earlier article. Familiarity with this article is therefore absolutely necessary to fully understand many of the statements presented here.

KEYWORDS: forensic science, IBIS™, correlator, error rate, electronic comparison, firearm markings

In the past few years, the IBIS™ electronic comparison system has become an important tool in numerous forensic firearm laboratories worldwide (1). This importance is reflected in a number of articles (2–14) that mostly either deal with practical recommendations on how to guarantee the system's successful operation or how to improve its results. These suggestions had been addressed to the user of the system as well as to its manufacturer.

Only a few open papers are known that have published performance results of the system. However, these studies are either outdated (15), because of considerable software improvements that have occurred since these publications, or have been performed with special/selected parameters, e.g., "class-clean" and "brand-clean" databases (see (16–19)), which do not reflect the "usual" working environment of an open case file. The results published in these reports—at least at first glance—appear to be contradictory: whereas Thompson (15) reports an IBIS™ success rate of as much as $p(5) \geq 0.9$ for cartridge case comparisons using a combination of breech face (BF) and firing pin (FP) markings, the other reports give much smaller values (e.g., George (17)), $p(10) < 0.25$, BF only) especially if one considers firearm markings on different brands of ammunition.

Presently, a publication is lacking, which, on the basis of sufficient data, allows one to judge the performance of the IBIS™ system in a realistic open case file database (OCFDB) application, which is also the standard field of application for this system. This gap should be closed with this paper.

A realistic open case file is generally characterized by a number of caliber groups of different sizes, a variety of firearm models that had been used to fire the evidence, a whole range of ammunition brands and a variable number of available bullets/cartridge cases per unrecovered firearm.

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Since the 1st of January 2001, the IBIS™ electronic comparison system has been used on a daily basis for the automatic comparison of firearm markings in the firearms identification service of the Federal Criminal Police Office (BKA), Germany. Sufficient experience is now available to enable an assessment of the reliability and the performance of the system during normal operation.

Without doubt, the essential task of the IBIS™ comparison system consists of finding matching marks on cartridge cases and bullets. For the comparison of new evidence ammunition with other (old) evidence ammunition from the open case collection, such matches indicate so-called "crime links." For the comparison of evidence ammunition with test ammunition from confiscated firearms, such matches indicate—but do not establish—"identifications."

Materials and Methods

Applied Sources

The performance of the IBIS™ comparison system can principally be accomplished through the subsequent verification of known crime links and identifications, thus enabling a conclusion regarding the reliability with which the system ascertains known matches.

For this purpose, the following data sources (a)–(d) were applied:

(a) *IBIS™ Test*: During the acquisition phase of the system, tests were conducted on it and were published in Rahm (20). Test databases were produced to determine the success rate of the system.
(b) *Retrograde Checking of Known Crime Links*: In the development phase of the IBIS™ at the BKA, which lasted through the entire year of 2000, there was a complete retrograde data acquisition of the evidence ammunition of all open cases. Additionally, there was a verification of all crime links in the collection, known from pre-IBIS™ conventional microscopic

comparison. This was performed to see whether known links would also result in a match with the IBIS™. For this paper, this verification was repeated with the latest software version. The results of this examination allow a realistic estimate of the success rate of the system during the search for crime links with respect to the work practice of the BKA.

(c) *Checking of Evidence Ammunition from the Same Firearm*: For the examination of evidence ammunition, examiners apply standard procedures. First of all, they determine the number of firearms used at a crime scene. If there are multiple cartridge cases or bullets available from the same unrecovered firearm, then, this provides another option to check the IBIS™ system. According to the procedural guidelines (see later) applied at the Forensic Firearms Service of the BKA, there should be—as long as this is available—data acquisitions of a maximum of three cartridge cases and two bullets from each unrecovered gun. The IBIS™ correlation of each single ammunition specimen then does not only run against the open case file, but also against all the other specimens fired from the same gun. In this way, the system, including the data acquisition process, undergoes latent checks. The results of this examination allow a realistic estimate of the success rate of the system under less-advantageous conditions ($k = 1$, see later).

(d) *Evaluation of "Warm Hits"*: In the course of examinations on evidence or test ammunition, police agencies occasionally provide hints concerning other offences, from which evidence ammunition is already accessible in the central collection. The examiners then follow these hints with conventional microscopic comparison methods. If these hints turn out to be true, there is a likelihood of verifying these "warm hits" with IBIS™, and thereby establishing a control of the system. The results of these examinations allow a realistic estimate of the success rate of the system for predicting identifications.

Tasks of the BKA Forensic Firearms Service

In the context of the topic being discussed here, only the relevant areas of the work of the BKA Forensic Firearms Service with respect to the open evidence collection will be addressed.

- *Evidence Ammunition Examinations (EAE)*: The foremost question here is: has the unrecovered firearm been used in other previous crimes (search for a "crime link")?
- *Test Ammunition Examinations (TAE)*: The foremost question here is: has the confiscated and test-fired gun been used in a registered previous crime (search for an "identification")?

The number of annual EAEs conducted by the BKA is presently approximately 500, and the number of TAEs approaches 5000.

Some Characteristics of the BKA's OCFDB

In contrast to model examinations, the parameters M, Q, i, k (see (1)) on which the success rate of IBIS™ depends for an OCFDB are not homogenous:

- For cartridge cases of caliber 22 l.r., only the ejector mark (EM) is exclusively analyzed. Insofar as fired cartridge cases of other calibers that do not show an examinable EM, only mark types BF and FP may be available.
- Although the IBIS™ system is only applied to ammunition that is "suitable for comparison" (see the subsequent section), there are inevitable differences in the quality Q of marks.
- The database size i of a caliber group constantly changes in the day-to-day work, however, with little variation.
- The number of available signatures of a certain mark type (e.g., BF, FP, EM) from the same unrecovered firearm used in a crime varies depends, in part, on how often the gun was fired, which causes a variation in the parameter k_{DB}.

The Parameter Q (Quality of Marks)

After receipt of evidence or test ammunition, the firearm expert conducts various examinations that do not need to be explained for the purpose of this study. However, the assessment of the "quality" of firearm markings to be processed with the IBIS™ system is important.

These are the three applied grades:

- Suitable for comparison;
- Partially suitable for comparison; and
- Unsuitable for comparison.

(a) Ammunition is *suitable for comparison* if from experience there is a sufficient probability that an existing match with specimens of the evidence collection can be recognized in a *normal optical comparison* with the human eye. This requirement goes further than that of being identifiable. This *de facto* means that an expert would be in a position to recognize similarities in two objects in a microscopic examination (magnification 5–20). Therefore, there must be characteristic marks that an experienced examiner memorizes and that he can find again in an optical mass comparison with other objects. This requirement for the "quality" of firearm markings may not be adequate for the use of the IBIS™ in a "Ballistic Fingerprint Database" (BFDB) application. It has, however, been applied in the BKA long before the introduction of the IBIS™ electronic comparison system. It has served since then as a necessary criterion for the admission of new evidence ammunition in the standard working collection.

(b) Ammunition is *partially suitable for comparison* if from experience there is a sufficient probability that—e.g., by following a given hint—a match with specimens of the evidence collection can be established. An identification appears to be possible based on "partially suitable" ammunition. In general, this requirement can be graded as "identifiable."

(c) Ammunition is *unsuitable for comparison* if there are either no marks present at all or if from experience the available marks do not offer any chance to identify the gun.

Only ammunition that is *suitable for comparison* will be analyzed with the IBIS™ system in the BKA. This demand is regarded as being essential for the use of any electronic preselection process. Table 1 shows the resulting actual share of the quality grades of the evidence collection of the BKA.

The Parameter i (Database Size)

Table 2 presents the actual distribution of the IBIS™ databases of the different caliber groups within the collection of evidence ammunition of the BKA. The sizes of the databases are relevant for the examination of sources (b)–(d).

For bullets, there are further subdivisions according to their class characteristics (number of lands and grooves, direction of twist, land width). The numbers given in Table 2, however, refer to the complete caliber group.

TABLE 1—*Distribution of the quality grades in the central collection of evidence ammunition of the BKA.*

	Suitable for Comparison (%)	Partially Suitable for Comparison (%)	Unsuitable for Comparison (%)
Cartridge cases	77	19	4
Bullets	35	51	14

TABLE 2—*Sizes of IBIS™ databases (as of August 2004) of the central evidence collection at the BKA, Germany.*

Caliber Groups	Cartridge Cases Parameter *i*	Bullets Parameter *i*
0.22 l.r.	142	—
0.38 Spec/0.357 Magnum	101	88
0.45 Auto/0.44/0.45	163	64
9 mm Browning short/9 mm Makarow	620	218
9 mm Luger/9 mm Browning long	1427	340
7.65 mm Browning (0.32 ACP)	1735	657
7.62 mm Tokarev/7.63 mm Mauser	323	Included above
6.35 mm Browning (0.25 ACP)	419	234
12 G	121	—
9 mm Knall (blank)	30	—
9 mm PA Knall (blank)	654	—
8 mm Knall (blank)	406	—

The Parameter M (Evaluated Mark Types)

For the comparison of cartridge cases, mark types BF, FP, EM are generally combined. Quite often, the mark type EM is not available for central fire ammunition, e.g., if the ejector imprint overlaps with the headstamp. For rim fire ammunition, only the IBIS™ ejector module is applied. For projectile comparison, MaxPhase (MP), MaxLea (ML) and PeakPhase (PP) are applied.

The Parameter k (Number of Available Signatures from the Same Source)

A maximum of two bullets and three cartridge cases from the same unrecovered firearm are acquired for the IBIS™ system for EAEs. For TAEs, one projectile and two cartridge cases (with the *most different* firearm markings) per firearm are used for the correlation. This defines the parameter k_{test}.

The parameter k_{DB} denotes the number of available signatures of the same mark type from the same unrecovered firearm in the open case file. Naturally, this number varies, depending on how many rounds had been fired from the same firearm at the crime scene.

An evaluation of the actual population size of the central collection of evidence ammunition of the BKA shows the following result:

- *Evidence Cartridge Cases*: For more than 54% of all shooting incidents, at least two cartridge cases from the same gun are available. In over 37% of all cases, at least even three cartridge cases from the same unrecovered firearm are available.
- *Evidence Bullets*: In 66.5% of all shooting incidents, only one single bullet is available. In the remaining part of 33.5%, there are at least two bullets available.

A mean value for the parameter k_{DB} can be determined for the central collection of evidence ammunition at the BKA as follows:

- For evidence cartridge cases: $k_{DB} = 1.92$; and
- For evidence bullets: $k_{DB} = 1.33$.

The Parameter n (Inspected Hit List Position)

At the BKA, the hit lists produced by the IBIS™ correlator have so far been inspected up to position 5. This means that up to hit list position $n = 5$, pictures of the evidence on the monitor are examined for similarities and if need be, the ammunition specimens are assessed under microscopic analysis. This rule has been fixed on the basis of the IBIS™ tests (Source (a)), at the beginning of the operational use of the IBIS™ system.

Summary of the Parameters for the Operation of the Central Evidence Collection of the BKA

Using the designation introduced in (1) the parameters given in Table 3 apply for the operational use of the central evidence collection of the BKA.

Results

For the presentation of the results of the performance tests, we selected the method outlined in (1): the success rate p will be plotted as a function of the hit list position n.

(a) *IBIS™ Test*: The commercially available electronic comparison systems at that time (1999) were all thoroughly examined and assessed. Also, the IBIS™ system went through an evaluation. In examining the performance of its comparison algorithm, a number of firearms of different caliber were test fired using ammunition of different brands. The specifications of the resulting 10 (small) databases are given in Table 4. For the test, all signatures were considered and compared independent of each other ($k_{test} = k_{DB} = 1$). For the cartridge cases, an assessment of the mark types BF and FP was preferred. The ejector module was not available at the time of this testing. The 0.22 l.r. cartridge cases were later examined with the ejector module. For bullets, the hit lists MP and ML were evaluated. The parameters of the IBIS™ test are summarized in Table 5. The results of the evaluations are shown in Fig. 1. This test only possessed a very limited strength because of the small sizes of the databases applied. The goal of the evaluation—also within a restricted time frame—was to determine the principal suitability of the system for an automatic preselection. Also, regarding the quality of marks, only good or even very good marks were chosen. All of these conditions favor the success rate.

(b) *Known Crime Links*: During the retrograde data acquisition of the complete collection of evidence ammunition of the BKA, signatures of approximately 5500 cartridge cases and about 2000 bullets were taken. There has been—and still is today—a row of known links in the collection that had been found by previous visual comparison work. These links were used to crosscheck the performance of the correlation process. For the purpose of this publication, this assessment was repeated with the complete set of still-available specimens in the evidence collection for which there is at least one crime link. In total, 232 of the actual existing crime links with cartridge cases and 84 existing links with bullets were assessed. Per mark type, over 670 correlations with cartridge cases and 180 correlations with bullets were carried out. In this evaluation, the procedures of the real timely sequence of the crime case analysis were also considered: if, for example, there is a

TABLE 3—*IBIS™ parameters of the central evidence collection of the BKA (as of July 2004).*

Task	B/CC	i	M	k_{DB}	k_{test}	n	Q
TAE	CC	Depending on caliber group (see Table 2)	BF+FP+EM	1..3	2	5	Suitable for comparison
TAE	B	Depending on caliber group (see Table 2)	MP+ML+PP	1..2	1	5	Suitable for comparison
EAE	CC	Depending on caliber group (see Table 2)	BF+FP+EM	1..3	1..3	5	Suitable for comparison
EAE	B	Depending on caliber group (see Table 2)	MP+ML+PP	1..2	1..2	5	Suitable for comparison

B, bullets; CC, cartridge cases; BF, breech face; FP, firing pin, EM, ejector mark; ML, MaxLea; PP, PeakPhase; MP, MaxPhase; TAE, test ammunition examinations; EAE, evidence ammunition examinations.

TABLE 4—*Sizes of the test databases for the IBIS™ test.*

Database/Caliber	Number of CC	CC from No. of Firearms	Number of Bullets	Bullets from No. of Firearms
0.22 l.r.	33	15	18	6
0.38 spec./0.357 Mag.	33	15	17	3
12 G	31	15	—	—
7.65 mm Browning (0.32 ACP)	19	6	25	5
8 mm Knall (blank)	33	15	—	—
9 mm Luger	21	6	27	12

CC, cartridge cases.

whole chain of links, the finding of a new link can be based on all available "chained" signatures in the database ($k_{DB} > 1$). In this sense, parameter values $k_{test} = 3$ and $k_{DB} = 17$ could be realized in one single case. The parameters of this test are summarized in Table 6, and the results are shown in Fig. 2.

(c) *Evidence Ammunition from the Same Firearm*: As already mentioned, during the examination of evidence ammunition, a maximum of three cartridge cases per unrecovered firearm and two bullets are considered. For the data acquisition, one chooses those objects that carry the most different firearm markings. In the correlation of the signatures, a certain mark type (e.g., BF) is compared with the complete set of elements of the database. It is also compared with the other signatures of the same unrecovered firearm. This provides the opportunity to check the IBIS™ correlator. For the evaluation, each signature is considered independent, i.e., $k_{test} = k_{DB} = 1$. The complete set of parameters of this test are summarized in Table 7. The results are shown in Fig. 3.

(d) *Checking of "Warm Hits"*: Upon submitting evidence or test ammunition, police stations occasionally point out links to other shooting incidents, when this knowledge arises during the investigation. Such links are always microscopically verified. If such a link leads to a "warm hit," then the IBIS™ system can be checked. The parameters of this test are summarized in Table 8, and the results are shown in Fig. 4.

Discussion

Choice of the Parameter n

As already mentioned in Table 3, the IBIS™ hit lists have been inspected up to position $n = 5$. The following question is justified: to what extent can the success rate be increased if the hit lists are inspected to a higher position? Table 9 provides an insight into what can be expected.

The increase of the success rate Δp for cartridge cases by doubling the inspected hit list position from $n = 5$ to $n = 10$ in all tests amounts to less than 6%. The possible increase rate of 20% for

TABLE 5—*Parameters for the IBIS™ test prior to its introduction at the BKA.*

Year	1997
SoftwareVersion: 2.0	
M	For cartridge cases of caliber 0.22 l.r. only EM For other cartridges BF+FP; for bullets MP+ML
Q	"Suitable for comparison" only; most of the firearm markings were of good or even very good quality. Mixed brands of ammunition
i	Values between 18 and 32 (see Table 2)
K	1 (each specimen was considered independent in the test)

BF, breech face; FP, firing pin; EM, ejector mark; ML, MaxLea; MP, MaxPhase.

bullets from crime links seems to be considerable, but this ensues from a relatively "low" level ($p(5) < 0.5$).

Comparing Mark Types M

Pointing out that all available mark types should be combined during the correlation evaluation to achieve the highest possible success rate is seen to be unnecessary. It is however, of interest to observe which mark types show the highest "selectivity," that is, which mark type contributes the most to the success rate of the IBIS™. The result of some model considerations can be found in Figs. 5 and 6. The data from retrograde crime links have been used for this evaluation (source (b)).

The results indicate that on average the evaluation of the FP impression makes the highest single contribution to the success rate of the IBIS™ during cartridge case examination, followed by the BF marks and the ejector module.

As can be expected, the success rates of ML, PP and MP only slightly differ from each other, and in their combination, they only score an approximately 10% higher value.

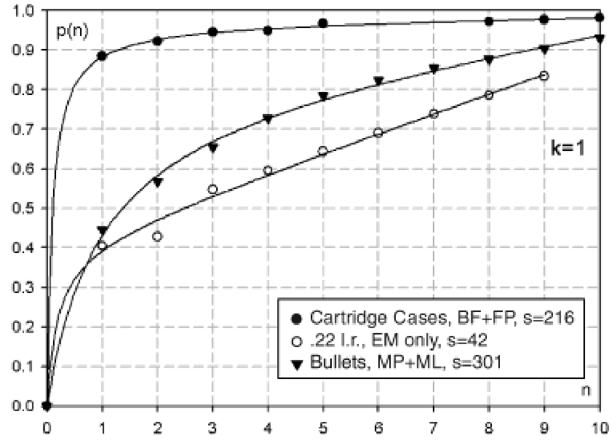

FIG. 1—*Success rate p as a function of the hit list position n for the IBIS™ test.*

TABLE 6—*Parameter values: checking of known crime links in the BKA central evidence collection.*

Year	2004 (renewed evaluation)
Software	Version: 3.2.151
M	Cartridge cases: BF+FP+EM; bullets: MP+PP+ML
Q	"Suitable for comparison" only; mixed brands of ammunition
i	Caliber groups according to Table 2
k_{test}	1...3; mean values: 1.16 for bullets, 1.51 for cartridge cases
k_{DB}	1...17; mean values: 1.66 for bullets, 2.40 for cartridge cases

BF, breech face; FP, firing pin; EM, ejector mark; ML, MaxLea; PP, PeakPhase; MP, MaxPhase.

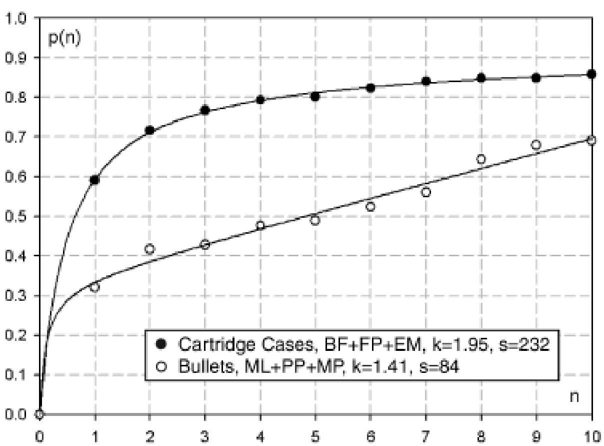

FIG. 2—*Success rate p of retrograde links as a function of the hit list position n.*

Effects of the Parameter k

For the correlation of evidence ammunition from the same firearm (Source (c), Table 7, Fig. 3), it is noticeable that the success rate *p* turns out to be less than for the other evaluations. The reason for this may be that "only" $k_{test} = k_{DB} = 1$ is valid.

The effect of an increase of the parameter *k* on the success rate *p* can even be better demonstrated by special evaluations. Since the use of multiple specimens from the same firearm for the purpose of a correlation in IBIS™ has so far been given only little attention by users (with the exception of (8) and (11)), this discussion will be slightly more detailed.

Among the evaluated crime links (Source (b)), there is a row of cases where a number of cartridge cases of the same unrecovered firearm are available, and for which $k_{DB} > 1$ can be achieved. In a specific evaluation, the success rate can be determined if one considers, on the one hand, only the result of single correlations ($k_{test} = k_{DB} = 1$) and, on the other, the specimens fired from the same firearm as a whole group (i.e., $k_{test} = 1$, $k_{DB} > 1$). An exemplary result of such an evaluation for cartridge cases of caliber 7.65 mm Browning (0.32 Auto) can be found in Fig. 7.

If one increases k_{DB} from $k_{DB} = 1$ to $k_{DB} = 4$, a corresponding increase in the success rate *p* can be seen. For this example, doubling k_{DB} approximately increases the success rate *p* by 10% or more.

A Comparison of Cartridge Case and Bullet Correlations

Comparing the results of correlations of cartridge cases and bullets, it is obvious that cartridge cases perform better (See Figs. 2–6). The reasons for this are as follows:

TABLE 7—*Parameters for the evaluation of evidence ammunition from the same firearm.*

Year	01.01.2001–02.08.2004
Software	Versions 3.2.151. 3.3; 3.4. 3.4.167; and 3.4.5
M	Cartridge cases: BF+FP+EM; bullets: MP+PP+ML
Q	"Suitable for comparison" only; mixed brands
i	Caliber groups according to Table 2
K	1

BF, breech face; FP, firing pin; EM, ejector mark; ML, MaxLea; PP, PeakPhase; MP, MaxPhase.

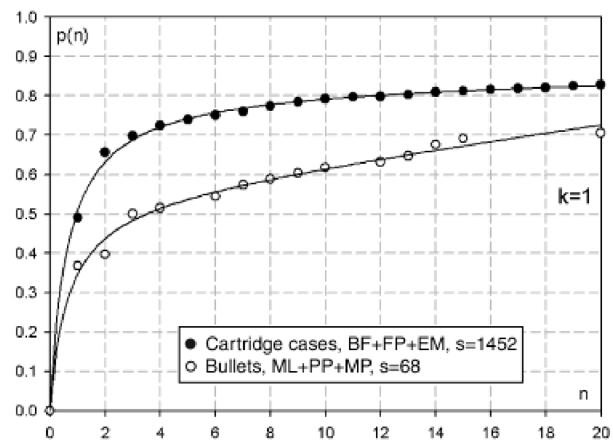

FIG. 3—*Success rate p for comparison of cartridge cases/bullets of the same firearm, as a function of the hit list position n.*

- The comparison of firearm markings on bullets using general visual optical methods is generally more difficult, and, therefore, a lower success rate is principally to be expected from an electronic system as well.
- The quality of marks on bullets is often worsened from the impact on a target.
- With bullets, only marks in the land impressions are examined, whereas for cartridge cases, there are three independent mark types at the examiner's disposal.

Summary

When operating a collection of evidence ammunition with the IBIS™ electronic comparison system, a success rate *p* in the area of 75–95% for cartridge case comparison and 50–75% for bullet comparison can be achieved in practice under certain conditions.

TABLE 8—*Parameters for checking "warm hits."*

Year	01.01.2001–30.06.2004
Software	Version 3.2.151. 3.3; 3.4. 3.4.167; and 3.4.5
M	Cartridge cases: BF+FP+EM; bullets: MP+PP+ML
Q	It should be noted that not all of the ammunition used in the evaluation could be graded "suitable for comparison." Identification/establishing a link by microscopic means, however, was always possible
i	Caliber groups according to 0
k_{test}	Mean values: 2.05 for cartridge cases, 1.18 for bullets
k_{DB}	Mean values: 2.28 for cartridge cases, 1.42 for bullets

BF, breech face; FP, firing pin; EM, ejector mark; ML, MaxLea; PP, PeakPhase; MP, MaxPhase.

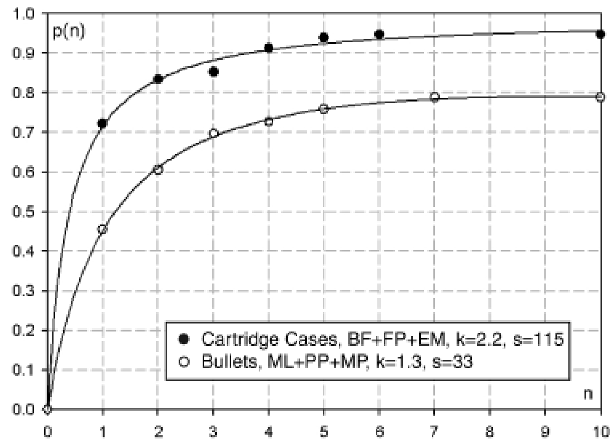

FIG. 4—*Success rate p as a function of the hit list position n for "warm hits."*

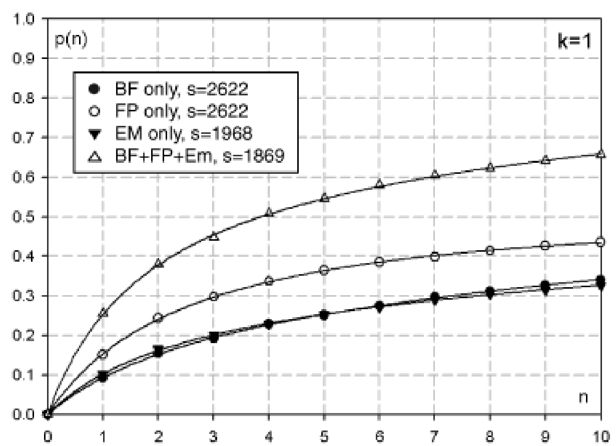

FIG. 5—*Cartridge cases: success rate p as a function of the hit list position n for mark types BF, FP, EM and their combination from retrograde crime links. BF, breech face; FP, firing pin; EM, ejector mark.*

A consideration of the hit list elements up to $n = 5$ or $n = 10$ appears to be sufficient. Evaluations that go further increase the workload and contribute little to the improvement in the success rate. The following conditions should be utilized when operating an electronic comparison system, as all of them have an improving effect on the success rate.

- Only ammunition with marks "suitable for comparison" should be introduced into an electronic system. This requires a pre-examination of fired ammunition components by an experienced examiner.
- The complete set of mark types (FP+BF+EM for cartridge cases, MP+ML+PP for bullets) should be combined in the electronic comparison. It has been found that for the evaluation of cartridge cases, on average the mark type FP provides the greatest contribution to the success rate. The manufacturer of the equipment has announced (AFTE 35th Anniversary Training Seminar, May 23rd–28th, 2004, Vancouver, Canada) an optimization of the comparison algorithm for FP marks. An improvement of the comparison procedure for BF marks would also seem necessary.
- As already stated in (1), the size *i* of the database of a caliber group should be kept as small as possible. This can be achieved through the sorting out of evidence ammunition after an expiration period.

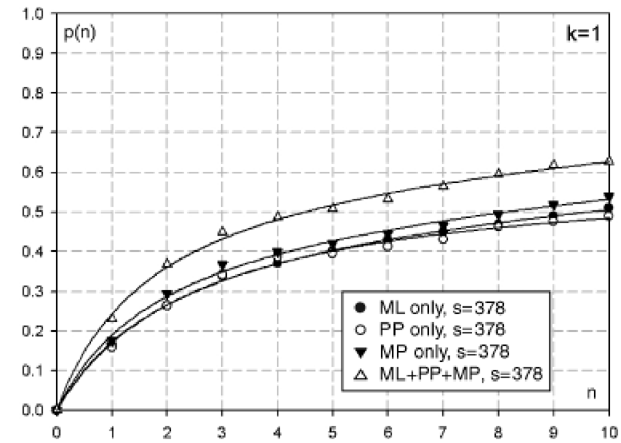

FIG. 6—*Bullets: success rate p as a function of the hit list position n for mark types ML, PP, MP and their combination from retrograde crime links. ML, MaxLea; PP, PeakPhase; MP, MaxPhase.*

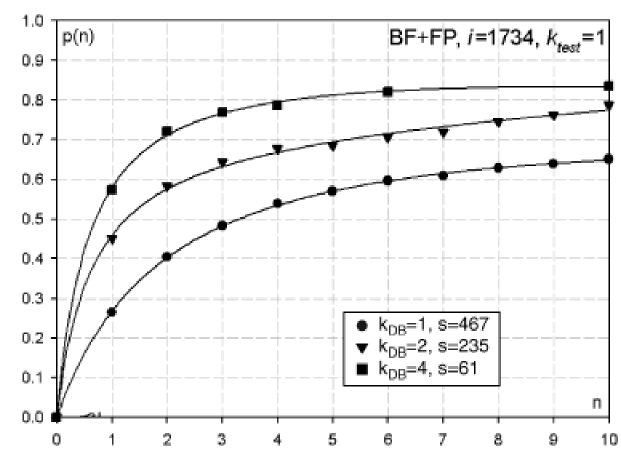

FIG. 7—*Model evaluation of the dependency of the success rate p on the parameter k_{DB} from retrograde crime links of cartridge cases caliber 7.65 mm Browning.*

TABLE 9—*Effect of the inspected hit list position n on the success rate p.*

Specimens	Source	Fig.	*p (5)*	*p (10)*	Δp
Cartridge cases	(b) Known crime links	2	0.802	0.858	0.056
Cartridge cases	(c) Evidence ammunition from the same firearm	3	0.740	0.793	0.053
Cartridge cases	(d) Checking of "warm hits"	4	0.939	0.948	0.009
Bullets	(b) Known crime links	2	0.488	0.691	0.203
Bullets	(c) Evidence ammunition from the same firearm	3	0.515	0.618	0.103
Bullets	(d) Checking of "warm hits"	4	0.758	0.788	0.030

- Multiple ammunition specimens of the same test firearm should be used for an electronic comparison ($k_{test} > 1$).
- If available, there should be more than one single (two, or, better yet, three) specimens of the same unrecovered firearm included in the setting up of the open case databases ($k_{DB} > 1$).

The last recommendation is contradictory to the demand of the smallness of the parameter i, but all in all an appropriate increase of the parameter $k = (k_{test} + k_{DB})/2$ will be beneficial to the success rate p.

Correlations on bullet marks are generally less successful than correlations on cartridge case marks. A new 3D technology has recently been announced by the manufacturer of IBIS™ (Bullet TRAX 3D, Forensic, Technology, Montreal, Canada), which will be applied to bullet marks. However, test results for this new method have not yet been published.

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