

White Paper

**Segmenting Tool Mark Image Reference Files
(TMIRF) To Identify Crime Guns More Effectively**



**FORENSIC
TECHNOLOGY**

A White Paper related to the concept of creating an electronic reference file containing digital images of the unique tool mark impressions left on fired ammunition components for the purpose of identifying crime guns, a concept sometimes referred to by the misnomer "Ballistics Fingerprinting"

CONTENTS

Contents	3
Abstract	4
Introduction.....	7
Background.....	9
Method One:.....	12
Method Two.....	14
What Else Does the Immediate Future Hold?	18
Conclusion.....	18
Final Note	18

ABSTRACT

With a vision of *crime solving through innovative technology*, Forensic Technology Inc. (FTI) employs over 350 professionals including engineers, technicians, and subject matter experts with expertise and experience in the areas of law enforcement and forensic science. The company's principal product is the Integrated Ballistic Identification System (IBIS®). IBIS is in use today by law enforcement agencies in 30 countries and territories throughout the world to collect, store, and analyze fired bullet and cartridge case **evidence** related to criminal investigations.

For the past 80 years, police have relied upon the science of "forensic ballistics"¹ to link fired bullets and cartridge cases to each other and to crime guns that were in police custody. The court-tested theory has remained unchanged. Every gun leaves unique microscopic markings on the surface areas of fired bullets and cartridge cases. Experts compare these markings in an effort to identify similarities that positively link them together, subsequently concluding that the ammunition components were fired from the same gun.

Harnessing the power of computers, IBIS technology captures digital images of the unique markings left on fired bullets and cartridge cases and sorts through them with lightning speed. IBIS technology then ranks the pieces of evidence with the highest likelihood of a match in order to maximize the productivity and effectiveness of the human expert element. Recently, much publicity has been generated around the concept of creating an electronic reference file containing digital images of the unique tool mark impressions left on fired cartridge cases for the purpose of identifying crime guns. Some people refer to this concept of creating a Tool Mark Image Reference File (TMIRF) by the misnomer "Ballistics Fingerprinting." Much of the discussion has centered on the issue of whether it is possible for automated forensic ballistics technology to accurately discriminate from among large

¹ "Forensic ballistics" is the layman's term for the science of firearms identification, which is primarily concerned with determining if fired bullets and cartridge cases, or other ammunition components were discharged from a particular firearm.

quantities of images that would be accumulated over long periods of time. Up to this point, the focus has been on the total reliance of the current matching algorithms of the technology and the efforts required by forensic examiners to interpret the results. However, there has been little discussion of alternative, complimentary, and practical methods that would be more effective in finding the “needle in the haystack.” Searching segments of a large TMIRF rather than the whole file would be more effective provided that the segments were the size of those that the technology (as it stands today) can manage efficiently.

Perhaps these issues have not been addressed because the concept has been considered from the technology perspective alone. There has been little deliberation from the standpoints of establishing efficient laboratory protocols and procedures and the leveraging of the criminal investigator’s expertise. In addition, the discussion has ignored the unquestionable fact that automated forensic ballistics technology, like all technology, will continue to improve at a rapid pace.

In this paper, we have considered these new perspectives and have identified two practical and effective ways that leverage the power of the technology to segment large TMIRF’s in order to identify probable matches in the most efficient and effective way.

These are:

- **Type Determination:** based on firearms class characteristics.
- **Zip Code Search:** based on the location of the first retail sale leveraged with crime gun intelligence.

Notwithstanding, correlation speed and algorithms have improved dramatically from the first introduction of automated forensic ballistics technology and will continue to do so. Since 1994, IBIS software has gone through a dozen significant software upgrades. With these upgrades, IBIS has been able to realize correlation speed increases of over 1,000 times. In addition, correlation performance has been significantly improved through the expansion of the types of marks

that can be correlated. Perhaps even more intriguing are the recent developments by FTI in the area of **three-dimensional imaging** and the demonstrated potential of “3D” in taking data search performance to levels never before achieved.

INTRODUCTION

The Integrated Ballistic Identification System (IBIS[®]) is in use today by law enforcement agencies in 30 countries and territories throughout the world to collect, store, and analyze fired bullet and cartridge case evidence and test-fires. As the backbone of the National Integrated Ballistics Information Network (NIBIN) in operation today in 235 police laboratories across the United States, IBIS is used for the analysis of fired bullet and cartridge case evidence related to criminal investigations.

IBIS has been proven to significantly increase the number of evidence matches made by law enforcement agencies, and to make matches that otherwise would not have been made. IBIS has also been shown to generate investigative actions that add value to ongoing firearm crime investigations and to facilitate information sharing within and across law enforcement agencies. Furthermore, IBIS has been shown in a study to generate a six-fold increase in the productivity of a forensic firearms lab.² Many examples of how IBIS has helped police in the United States as well as in other countries around the world to better do their jobs can be found under the category of *success stories* on the web sites of the Bureau of Alcohol, Tobacco, Firearms and Explosives (www.atf.gov) and Forensic Technology Inc. (www.forensictechnologyinc.com).

Recently, much publicity has been generated around the concept of creating an electronic reference file containing digital images of the unique tool mark impressions left on fired cartridge cases for the purpose of identifying crime guns. Some people refer to this concept of creating a Tool Mark Image Reference File (TMIRF) by the misnomer "Ballistics Fingerprinting." Much of the discussion has centered on the issue of whether it is possible for automated forensic

² "Assessing the Value Added to Firearms Enforcement Operations By Ballistic Imaging Technology" by Dr. Anthony A. Braga, Harvard University and Dr. Glen L. Pierce, North Eastern University

ballistics technology to accurately discriminate from among large quantities of images that would be accumulated over long periods of time. Up to this point, the focus has been on the total reliance of the current matching algorithms of the technology and the efforts required by forensic examiners to interpret the results. However, there has been little discussion of alternative, complimentary, and practical methods that would be more effective in finding the “needle in the haystack.”

FTI has been involved in studies of this TMIRF concept, and its accompanying technology is in use by two states with laws requiring the implementation of the said concept. As a result, FTI is continually consulted regarding this concept and for FTI’s technological expertise in this area. As a company whose technology has become the world standard in forensic science firearms identification, we are proud of our partnership with law enforcement. Our interest is in seeing our technology discussed and described accurately and used to its greatest crime-solving potential. For these reasons, we feel compelled to produce this paper.

BACKGROUND

A Tool Mark Image Reference File (TMIRF), is an electronic reference file containing digital images of the unique tool mark impressions left on fired cartridge cases for the purpose of identifying crime guns. The concept involves the capturing and storing of electronic images and critical data from the bullets and cartridge cases of test-fired firearms **before** these firearms are sold to the public, or more specifically, before the firearm moves from lawful possession and use to criminal possession and misuse.

Currently, two states, Maryland and New York, have laws that require the creation of what is in effect, a TMIRF, and both states operate them in similar ways. Firearm dealers in these states are required to submit a test-fired cartridge case to the State Police from the handguns that they sell. Most often the manufacturer of the firearm, as required by law, has already included (in the box with the gun) the test-fired cartridge case(s) in an envelope that is marked with certain information including the make, model, and serial number of the firearm. The State Police then use ballistics technology to capture the digital images of the unique tool marks left on the fired cartridge cases. The result is the creation of a TMIRF of tool mark images linked to the serial number of the gun that fired it. This digital volume can then be queried with the images of ballistics evidence from crime scenes and crime guns in order to learn the make and serial number of the firearm that fired them. With this information, the firearm can then be traced by law enforcement agencies through normal channels to the first known purchaser in order to begin tracing the history of the gun from legal purchase to criminal misuse. This concept has been in place for two years and is already proven itself with four matches in Maryland. This is an interesting result especially considering that the average time that it takes for a new gun to go from first legitimate purchase to misuse in crime ranges between four to six years. This phenomenon called "time-to-crime" can vary widely according to the circumstances.

While it is clear that this concept has been proven to function as designed, debate continues to surround the fact that tool mark image data of the same caliber will mount over time. These images must be stored in a TMIRF for later query. Currently, IBIS technology searches for matches using filters based on caliber and the date the crime occurred. It utilizes a robust correlation algorithm to discriminate between casings. From this, it creates a list of most probable matches. The question under debate is: *Can a piece of evidence be matched to the reference exhibit stored in a TMIRF made up of thousands or millions of exhibits in an efficient and effective way?*

Although exhaustive tests have yet to be conducted that test the full capability of the current discriminating power of IBIS technology, practical experience has given us some indication as to how well IBIS is performing the task of searching criminal evidence image data in the real world. Actual field data shows that IBIS is efficiently and effectively conducting searches in a database containing over 85,000 exhibits. Current system protocols segment the database by caliber family. The largest single caliber segment in that database represents about 10,000 nine-millimeter cartridge cases. The forensic experts conducting queries of the database credit IBIS with enabling them to produce a continuous stream of positive identifications found within the top five listed candidates.

While this information gives us an idea of what is being done with large volumes of **criminal evidence image** data, it still does not answer the question as to how large a typical TMIRF could grow to within one, two, three, or more years.

According to information reported by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) in a publication entitled the "Annual Firearms Manufacturing and Exportation Report,"³ there were 213,378, nine-millimeter pistols produced by 71 manufacturers in the year 2001.

³Prepared by the Office of Firearms, Explosives and Arson, Bureau of Alcohol, Tobacco and Firearms, Washington, DC: *Annual Firearms Manufacturing and Exportation Report (AFNER), 2001 [Does not include imported firearms]*

According to the report, the 9-millimeter pistol represented the largest category of pistols made. Could we develop a rough order of magnitude estimate of how many 9-millimeter pistols are sold in a state each year? To get a rough number for discussion purposes, we can mathematically distribute the number of 9-millimeter pistols made in 2001 according to the percentage of population that each state represents of the whole U.S. population. The following represents our findings:

California as the most populated state would have the largest number of 9-millimeter pistols at about 22,000. California would be followed by Texas at 14,000 and New York at 12,000. The numbers then begin to drop rapidly after New York.

Certainly we know that there are many other factors that affect this distribution beyond just percentage of population. However the estimate is useful to illustrate a best guess according to a practical assumption that the total number of firearms produced each year would most likely be distributed among the 50 States.

This paper will use the rough order of magnitude number of 22,000 for California 9-millimeter pistols as an example of large TMIRF and how it could be segmented through the use of two very practical methods.

METHOD ONE:

Type Determination Based On Firearm Class Characteristics

Before we can understand the full value of segmentation of data into smaller search segments, we must first understand how IBIS technology works. In fact, IBIS already uses some basic segmentation filters such as caliber and the date that the crime occurred. IBIS does not correlate or search in order to determine a prospective match between two components of different caliber families. For example, IBIS will only search a component member of the 9-millimeter caliber family against another 9-millimeter caliber family member. It will not search a 9-millimeter family against a .22 caliber family. IBIS also takes dates of occurrence into account when searching evidence against test-fired specimens from guns that have been in continual police custody since before the crime in question occurred. This limited segmenting of the data is done to create better efficiency and effectiveness in the matching capability of the algorithms.

Some manufacturers make their guns with distinctive general class characteristics such as a uniquely shaped firing pin that leaves distinctive marks on the fired ammunition components that enable firearms examiners to positively identify the manufacturer. Experts have done work cataloging the many different markings that particular firearms leave on fired ammunition components in order to predict the manufacturer of the firearm. They call this type of prediction “Type Determination”,⁴ a term attributed to German experts.

In *The Matrix: 9mm Parabellum - An Empirical Study of Type Determination*,⁵ the author Robert H. Kennington uses a matrix of Breech Face Marks, Drag Marks, Ejector Marks, Firing Pin Shapes, Firing Pin Impressions, to compare the marks left on 9-millimeter fired ammunition components in order to predict the manufacturer of the

⁴Author: Robert H. Kennington: *The Matrix: 9mm Parabellum – An Empirical Study of Type Determination*

⁵*Ibid*

gun that fired them, or at least narrow the suspect field down to just a few possibilities. Although the author is careful to note that the odds are somewhat against the identification of a single weapon, he at the same time expresses confidence that the matrix can be used to greatly narrow the field of possibilities.

Kennington's Matrix identifies at least 22 different kinds of Firing Pin Impression features alone, and there are multiple categories within the other major features such as breech face marks and firing pin shapes as well. Therefore, one could imagine using the 22 different Firing Pin Impression features as just one way in which to segment a data set of 22,000 exhibits. A "best case" scenario using simple arithmetic for illustration purposes only shows that on average the data segment to be searched could be as small as 1,000 exhibits rather than 22,000 when divided by 22.

The possibilities are even more interesting when one considers the many kinds of impressions (e.g. dimpled, mottled, and both dimpled and rough), that in combination with other major features such as firing pin shape and breech face marks can work out to many more combinations than the 22 used in the example above. Therefore, type determination based on class characteristics can be a very effective method in helping to segment large TMIRF's. This method can also provide valuable information to police investigators to help them in the tracking of crime guns.

METHOD TWO

Zip Code Search Based On The Location of First Retail Sale and Leveraged With Crime Gun Intelligence

We can make a relatively safe assumption that the first retail sale of a firearm is made by a Federal Firearms Licensee (FFL). Knowing the location of sale can be an important factor in segmenting large TMIRF's. In a report entitled "Firearms Commerce In the United States 2001/2002"⁶, ATF provides the number of FFLs by State.

There are 6,093 FFLs located throughout California. FFL location is important because as previously stated: Maryland and New York have laws that require something akin to the creation of TMIRF's. Firearms dealers in these states are required to submit a test-fired cartridge case to the State Police from the handguns that they sell. The State Police then use ballistic technology to capture the digital images of the unique markings left on the fired cartridge cases. The State Police could just as easily also record the zip code of the FFL submitting the cartridge cases thereby enabling the segmenting of the TMIRF by zip code in order to help speed the IBIS correlation process. If other States were to follow the Maryland and New York methodology, there would be more FFLs submitting more test fired cartridge cases to more State Police agencies. The zip codes can be a way of categorizing the exhibits by location and of segmenting the TMIRF's into smaller searchable elements.

Because of the way that the Zip Code schemes are constructed, they may be well suited for use in executing search criteria for segmentation of TMIRF's by location of firearm sales. Queries can be run on parts of the zip code that can expand the search area from a city block to a major region to the entire State or multiple States.

⁶Produced by the U.S. Department of Treasury, Bureau of Alcohol, Tobacco, and Firearms: *Firearms Commerce In the United States, 2001/2002*

The optimum benefit of segmenting the TMIRF search using zip codes is achieved when the decision as to which zip code or codes to search on is based on crime gun intelligence information. The ATF Youth Crime Gun Interdiction Initiative (YCGII) crime gun trace reports for the year 2000 clearly show that there are many repeatable patterns and trends identified in the criminal misuse and movement of crime guns. This crime gun intelligence information can be leveraged with technology to provide actionable intelligence and a useful segmentation tool as well. This will require better information sharing and closer collaboration between forensic and investigative personnel. The following types of crime gun intelligence gleaned from the ATF Crime Gun Trace Reports could be used to leverage the segmentation and search by FFL location⁷:

- **Source to Recovery Location.** Crime guns usually are found in cities. However, many guns move from regional and national sources. Regional trafficking consists of guns moving to a city from neighboring states, while national trafficking involves guns moving from more distant states.
- **Regional Patterns.** Washington, DC, which does not allow handgun sales to residents, and has city limits bordering two other states, is the extreme case of regional trafficking with 58.5 percent of crime guns coming from neighboring states.
- **National Patterns.** National trafficking patterns account for 30 percent or more of guns traced from nine cities. The most striking case is that of New York City, where 73.4 percent of crime guns came from national sources including Virginia,

⁷Produced by the U.S. Department of Treasury, Bureau of Alcohol, Tobacco and Firearms: *Crime Gun Trace Reports (2000) National Report*, Published July 2002.

- North Carolina, Georgia and Florida. Newark and Jersey City, which are located near New York, experience strikingly similar national trafficking patterns with 80.2 and 74.5 percent of their crime guns coming from national sources.
- **Concentration of Gun Traces Among Dealers.** Crime guns are not only concentrated by region, state and county, but also by the Federal Firearms Licensee where the firearms were originally sold.
- **City variations.** In all jurisdictions, many traceable crime guns were first purchased from a small number of federally licensed gun dealers. Some cities exhibited a very high concentration of crime gun traces. In Indianapolis, IN, 70 percent of traceable crime guns were first purchased at ten federally licensed gun dealers.
- **Distance from Originating Location to Recovery Location.** Another measure of the mix of local, regional, and national transactions is the distance in miles between the recovery location and the originating location.
- **City variations.** Cities varied considerably in the distance between the crime gun recovery locations and the location where the guns were first purchased at FFLs. In certain cities, the majority of the crime guns were first purchased at FFLs that were ten miles or less from the crime gun recovery locations. These cities included: Baton Rouge, LA (70 percent); Gary, IN (70 percent); New Orleans LA (67 percent); Louisville, KY (64 percent); Pittsburgh, PA (63 percent).

Armed with this information, the police can construct an escalating continuum of queries to segment a TMIRF into locations where statistics have shown to be the most probable legal sales outlets for the guns that later turn up in crimes within a particular area. **This in no way suggests that gun dealers are doing anything wrong; rather it**

suggests that people tend to exhibit repeatable patterns of behavior (e.g. shop at the same store, frequent the same barber, etc.) the goal here is to catch criminals, not interfere with legitimate commerce.

Using search queries based on location of sale can efficiently and effectively accomplish this escalating continuum. Further, geographic location can be useful in connecting criminal activities related to organized criminal groups such as gangs, which operate within an established "turf", or geographic area.

Therefore, crime gun trace reports and other similar types of information can provide police in many cities with very good intelligence about repeatable patterns and trends of crime gun possession and movements as they relate to their specific jurisdictions.

WHAT ELSE DOES THE IMMEDIATE FUTURE HOLD?

Since the beginning of 1993, when the first ballistic imaging systems were fielded, the complexity, speed, accuracy and global performance of the correlation algorithms have been improved dramatically and will continue to do so. IBIS software has gone through a major rewrite and 11 significant software upgrades. With these upgrades, IBIS has been able to realize correlation speed increases of over 1,000 times. In addition, correlation performance has been significantly improved through the expansion of the types of marks that can be correlated. Perhaps even more intriguing are the recent developments by FTI in the area of **three-dimensional imaging** and demonstrated potential of “3D” in taking data search performance to levels never before achieved.

Conclusion

We have identified two immediately available, practical, and effective ways to Segment Large Tool Mark Image Reference Files:

- Type Determination: based on firearm class characteristics
- Zip Code Search: based on the location of first retail sale

Furthermore, the technology has made significant improvements since its first introduction over ten years ago and continues to so.

Final Note

As humans we do not and should not expect technology to operate without any limitations or human intervention. For example, today’s police body armor will not stop every conceivable bullet threat. That does not mean that police should not wear body armor. Body armor provides an acceptable level of protection against certain threats that make it worthwhile for police and soldiers to wear. To make the most effective use of technology, we must stay continually aware of what technology can do and what it can’t do. We can then innovate in order to realize even higher levels of efficiency and effectiveness from

technology by integrating and leveraging its use with such things as tactics, experience, intelligence, protocols and procedures, and even other technologies.

In the meantime, automated forensic ballistics technology will continue to advance and achieve the level of our expectations by automating more and more processes just as technology has done in every other field. Expanding on the body armor analogy, even though they may wear body armor, police still train rigorously on tactics to minimize their target profile and to use cover and concealment methods when facing a firearm threat. In addition, many body armor systems allow for the integration of steel and ceramic inserts to provide added levels of protection. Adjustments and improvements to existing technology can compensate for limitations. Automated forensic ballistics technology functions in the same way and can be adapted to surmount challenges.

At FTI we steadfastly believe that technology is critical to winning the war on crime, and we are committed to research and development efforts that bring together experts in forensic science, law enforcement, and technology to create new crime fighting solutions. We see ourselves among the visionaries, among those who try and fail, and then try and try again. We are innovators at FTI and we are proud of it. Our resolve is echoed in these words about the concept of human flight:

“There shall be wings! If the accomplishment be not for me, 'tis for some other. The spirit cannot die; and man, who shall know all, shall have wings”.

Leonardo da Vinci

