Extracting Ballistic Forensic Intelligence: Microstamped Firearms Deliver Data for Illegal Firearm Traffic Mapping – Technology

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ABSTRACT

Over the years law enforcement has become increasingly complex, driving a need for a better level of organization of knowledge within policing. The use of COMPSTAT or other Geospatial Information Systems (GIS) for crime mapping and analysis has provided opportunities for careful analysis of crime trends. By identifying hotspots within communities, data collected and entered into these systems can be analyzed to determine how, when and where law enforcement assets can be deployed efficiently. This paper will introduce in detail, a powerful new law enforcement and forensic investigative technology called Intentional Firearm Microstamping (IFM). Once embedded and deployed into firearms, IFM will provide data for identifying and tracking the sources of illegally trafficked firearms within the borders of the United States and across the border with Mexico. Intentional Firearm Microstamping is a micro code technology that leverages a laser based micromachining process to form optimally located, microscopic “intentional structures and marks” on components within a firearm. Thus when the firearm is fired, these IFM structures transfer an identifying tracking code onto the expended cartridge that is ejected from the firearm. Intentional Firearm Microstamped structures are laser micromachined alpha numeric and encoded geometric tracking numbers, linked to the serial number of the firearm. IFM codes can be extracted quickly and used without the need to recover the firearm. Furthermore, through the process of extraction, IFM codes can be quantitatively verified to a higher level of certainty as compared to traditional forensic matching techniques. IFM provides critical intelligence capable of identifying straw purchasers, trafficking routes and networks across state borders and can be used on firearms illegally exported across international borders. This paper will outline IFM applications for supporting intelligence led policing initiatives, IFM implementation strategies, describe the how IFM overcomes the firearms stochastic properties and explain the code extraction technologies that can be used by forensic investigators and discuss the applications where the extracted data will benefit geospatial information systems for forensic intelligence benefit.

Keywords: Tagging, Microstamping, Ballistics, Forensic Intelligence, Intelligence Led Policing, Security, Firearms Trafficking, Border Security, Optical Tagging
1.0 FIREARM MICROSTAMPING
1.1 MICROSTAMPING TECHNOLOGY

Intentional Firearm Microstamping (IFM) is a method of placing intentional codes linked to the serial number of a firearm by means of an “optimized micromachining” process. The codes are placed into surfaces of a firearm that transfer information onto cartridge cases expelled during the firing process. These codes are formed as micro-embossing structures, which come into contact with a cartridge that is cycled through the firearm and ejected when fired. The goal is to provide an improved piece of trace evidence for forensic investigators that can help track a firearm without having to recover it.

Transferring of unique markings such as letters and numbers has been around for many centuries. The Gutenberg press could be considered the first instance where a formed or molded set of alpha-numeric characters was used repeatedly to transfer unique marks from one medium to another. In this case, ink laden molds of characters were pressed onto paper. Preceding the printing press by hundreds and even thousands of years, artisans have been embossing metal surfaces as well as many other materials. One of the best known embossing tools was used by the Ancient Greeks to wax seal envelopes, which had finely detailed feature sizes down to 200 µm.

As for Intentional Firearm Microstamping, the mechanics or physics of transfer have not changed. We are still dealing with uniquely formed characters, such as letters, numbers or encoded geometric codes that require a force or pressure to achieve a transfer to a material softer than the formed characters themselves.

Just like the Gutenberg press, firearm microstamping is not new. Firearms currently microstamp unintentionally which is an attribute shared by all firearms for more than a hundred years. Today’s Intentional Firearm Microstamping is just an enhanced version of a well understood process that has been optimized and applied to firearms with identifiable micro-code structures. Figure 1 shows a Firearm Microstamp tool mark on a primer and the breech face of a brass cartridge.

![Figure 1: Primer and Head Stamp IFM Code (Firing Pin / Breech Face)](image)

1.1.1 UNINTENTIONAL TOOL MARKS “Traditional Firearm Identification Methods”

Since the early 1900’s firearm and tool mark examination techniques have been based on the analysis of unintentional or randomly formed marking surfaces which transfer to the surfaces of ammunition components.
These unintentional transferred marks on the surfaces of the cartridge and the projectile take the form of striations (scratches and indentations). Because they are randomly formed by the machining processes that are used to manufacture the firearm, these unintentional marking surfaces are not optimized to produce uniquely resolvable striae specific to the dynamics of the firearms mechanism. This means that unintentional microstamped features are nondescript, have little readily resolvable repeatability and rely on the recovery of its matching firearm to make them useful during the traditional tool mark forensic identification process.

Yet, such unintentional tool marks have been accepted as reliable for identification of firearms associated with crimes by US Courts. However, a recently announced congressionally mandated report from the National Research Council (NRC), of the National Academy of Science, finds serious deficiencies in the nation's forensic science system and calls for major reforms and new research [1]. With the exception of DNA analysis, the report states that no other forensic method has been rigorously shown to be able to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source. This report specifically outlines the shortcomings of traditional firearm and tool mark analysis which relies solely on unintentional tool marks that are neither optimized to the firearms dynamics nor purposeful in their application. One factor that clearly differentiates the power of Intentional Firearm Microstamping from traditional matching is the fact that intentional tool marks are the only type that can be quantitatively and uniquely analyzed.

### 1.1.2 INTENTIONAL TOOL MARKS

Intentional Firearm Microstamping (IFM) creates a new opportunity for the evolution of traditional firearm and tool mark analysis. IFM differs from unintentional microstamping because within the intentional process, micron level features are actually optimized to the multivariate and dynamic behavior of the firearm mechanism being outfitted. Through a highly evolved optimization protocol developed over the last fourteen years, a firearm model is tested to determine specific intentional microstamping geometries, such as character height, width, separation, surface finish, depth, draft angle and their arrangement within the firearm for optimum transferability and durability. Specific font structures have been created to allow for enhanced optical character recognition with Intentional Microstamped cartridges. The optimization routine delivers a higher level of transfer in comparison to unintentional microstamping, which in most firearms has been observed to be incapable of repeatability down to the last striae over repetitive firings [2]. In light of the recent NRC report on forensic science, the poor repeatability of the unintentional tool marks means that the unintentional process is far from reliable from a scientific basis.

Intentional Firearm Microstamping features are truly intentional and tested against the specific behavior of each model of firearm. They naturally provide a higher level of transfer performance, survivability and repeatability. The optimization routine takes into consideration explosive impact forces, extreme pressure, intense heat, caustic gases, vibrations and violent mechanical shear stresses encroaching on the cartridge from multiple vectors. All these variables converge simultaneously to affect the ability of IFM features to replicate characters or encoded geometries into the targeted cartridge surfaces [3].

What becomes clear is that Intentional Firearm Microstamping isolates variability through the optimization of the tool mark by incorporating a mix of customized fonts, angular orientations, formats of the code sequences and carefully chosen code locations. IFM’s success as a forensic tool derives from understanding such optimized details that can then be designed into the Microstamp structure. Couple this to a carefully
developed forensic method of code extraction, and the success rates for retrieving trace evidence in a quantitative way with high certainty values delivers exceptional results. Trace evidence results from Intentional Firearm Microstamping far exceed those of today’s traditional firearms matching methods.

By design, Intentional Firearm Microstamping becomes a forensic method for gun tracing akin to the robustness resulting from the forensic method for DNA analysis. Intentional Firearm Microstamping provides a consistent and high degree of certainty when looking for the connection between firearm evidence (e.g. fired cartridge found at a crime scene) and a specific firearm source, because these are the only kind of toolmarks that can be quantitatively and uniquely analyzed without the need to recover the actual firearm source.

1.2 THE NEED FOR DE-CENTRALIZATION OF FIREARM TRACING

“Did we make the right decision?,” is a question asked by many managers and department heads within law enforcement and a question made even more poignant since the terrorist attacks on September 11th 2001. The 9/11 Commission’s report specifically states that there were problems with how law enforcement collected, analyzed and acted on data prior to the terrorist attacks. A concise summary statement that truly encapsulates the issue prior to 9/11 states, “[United States law enforcement] Agencies uphold a ‘need-to-know’ culture of information protection rather than promoting a ‘need-to-share’ culture of integration” [4] [5]. Bureaucratic structures tend to be inflexible by default, with unnecessary complexity wrapped in centralized control. One way agencies attempt to create flexibility in their operations is by forming task forces where a team is integrated using local, state and federal law enforcement personnel. The problem is most task forces are limited in scope and duration due to financial restrictions and political pressures.

A system that has been very effective is the National Trace Center (NTC) at tracing recovered firearms. The NTC is a centralized system operated by the Bureau of Alcohol, Tobacco, Firearms and Explosives which traces the source of firearms found at crime scenes. This NTC, which was state of the art nearly 10 years ago, has not addressed the emerging threats from narco-terrorists at the US borders, such as organized crime networks with border ties and gang activity within the large inner cities. A new system must be implemented to increase the speed of firearm identification and tracing to provide opportunities to target these newly entrenched criminal networks.

Many large cities and even smaller suburb towns are dealing with the tentacles of the these criminal networks spreading into their jurisdiction. Community led policing isn’t enough, requiring local and state law enforcement groups to change to intelligence-led policing techniques to be able to keep up with the criminal infiltration. Facing a tipping point, state law enforcement agencies now require their own data collection and analysis systems through modified GIS or CompStat style computer platforms so that they can foresee and counter rapidly emerging threats. A principal limitation of the NTC is the fact that a physical firearm is needed to make effective traces. Once a firearm is recovered its serial number is sent to the NTC to be identified, but often the leads goes cold that point. Further investigation is often needed to make the trace useful, but continuing is at the sole discretion and availability of special agents of the BATFE [6]. Such decisions can create conflicts of interest when the state believes its data and emerging needs are a priority, but the BATFE weigh the value of further investigation and determines that in light of the budgetary and congressional mandates that create legal and regulatory restrictions [7], the trace falls short of additional follow-up.
As observed in the news, federal law enforcement is spread too thin. This was evident post 9/11 which led to
the formation of the Department of Homeland Security (DHS). DHS is considered the solution to leverage
state law enforcement and its structure offers the opportunity to create a new type of trace group that could
handle the information generated from new Firearm Microstamping technology. On the other hand, state law
enforcement could develop its own trace channels or be provided with a trace interface platform from DHS
that could allow state law enforcement to quickly access trace information and integrate it with their localized
computer systems to create intelligence that can be acted upon more quickly. This new local information can
also be shared with DHS and BATF through such shared access to the trace platform, where it can be
integrated into a broader national security analysis system. This gives DHS more data for the broader
national analysis and the ability to cross compare it with other regions of the country. Once DHS begins to
handle Microstamping crime data, it can then be interfaced to the NTC system which should remain in service
because it already handles the pre-microstamping firearms which will continue in circulation.

Cross border firearm trafficking is a Homeland Security issue and it makes sense to develop trace capability
at DHS to tackle interstate and cross border firearm trafficking activities. De-centralization is critical for
intelligence-led policing and with DHS interfacing with state law enforcement together they can more
efficiently allocate resources. BATFE’s NTC system meets the needs of tracking domestic firearms traffic by
domestic criminal organizations. A new system utilizing IFM implemented by DHS could provide far more
capability to address unique priorities for local law enforcement [5]. Figure 2 shows the association of known
and potential trafficking interaction available from firearm traces [7].
1.3. IFM BENEFITS AND APPLICATIONS: GEOSPATIAL INFORMATION SYSTEMS

“What are Geospatial Information Systems (GIS)?” Many law enforcement professional are aware of programs such as CompStat used by the Los Angeles Police Department (LAPD). A GIS is a computer system used to capture, manage, integrate, manipulate, analyze and display data which is spatially referenced to the Earth [8] [9].

The power of GIS is in the data that is input into the system, special care should be taken to ensure that there is consistency in data formats. With GIS there is an opportunity to integrate firearm trace data locally, nationally and internationally to counter emerging threats that are asymmetric to normal criminal behavior and patterns. Ironically, much of the crime related knowledge and information that police departments create is rarely used internally [5] and is quickly lost due to a lack of computer software that can process the legitimate intelligence information while it looks for patterns. To make matters worse, many departments lack basic computer systems capable of distributing the data to command staff and line who might be able to utilize the information on the streets.

Intentional Firearm Microstamping provides an opportunity for GIS by capturing data on the existing recovered firearms as well as recovered microstamped cartridges. With IFM, it’s the cartridges themselves that will provide the freshest intelligence possible on firearm trafficking patterns. By increasing the number of data points, a dedicated GIS platform will begin to evolve a model of the dynamics and evolution of firearm trafficking patterns. These patterns will begin to expose criminal trafficking networks and then will show how criminals adapt to the pressures brought on because decisions law enforcement begins to make once empowered by good intelligence. The key is to develop process models that can anticipate or identify problem areas in real-time (as they emerge) instead of years after later [10]. The key is to interconnect multiple databases into GIS systems that can paint a picture of the multiple layers in which criminal activities interrelate with gun and drug trafficking to provide a comprehensive viewpoint for law enforcement. More data equals more opportunities to stop the flow of trafficked firearms.

1.3.1 SPATIAL INFORMATION

The two obvious spatial data points provided by a microstamped cartridge is the firearm source location and the crime scene location where the cartridge is found. The start and end points determine a straight line traffic route for that particular firearm. As more and more firearms are traced the spatial data set will begin to show patterns. Other patterns will also emerge, especially if the firearm is used numerous times. Each new crime scene where the firearm is identified using the microstamp will provide additional mapping opportunities, showing how the criminals firearm moves within a city, a state or across a border. Like most people, firearms traffickers are creatures of habit, and they often establish specific patterns in their activities. They might prefer a certain type of straw purchaser, a specific source location or licensee, or a favorite method of distribution. They typically change their pattern of activity only when forced or when they no longer feel comfortable or safe. Firearm trafficking becomes vulnerable to certain law enforcement techniques when an analysis of the recoveries identifies spatial patterns [11].

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1.3.2 Temporal Information

The use of a timeline can become an effective tool. Time-to-crime of a firearm is the time it takes from the purchase of a firearm to the first time it is used to commit a crime. If the firearm is not recovered, but can be identified with IFM, then that first data point will serve as a baseline position for that person who has the firearm. If the firearm is subsequently used again, another timeline data point is created, providing information on intra-city or interstate routes of travel. This type of data can be integrated with other types of data on known suspects or even social networks (known associates) [12]. The timelines developed in relation to firearm trafficking provides specific precision, intra-connection, and focus to the information as a whole. When dealing with organized crime and specifically with urban gangs who have established drug distribution territories within cities, the data gleaned provides specific intelligence on gang strength, locations of operation, trafficking routes, modes of travel (vehicle, walking) and types of guns.

![Figure 3: CompStat GIS – LAPD System [13]](image)

2.0 Optimization and Implementation

2.1 Optimization to Firearms

Dynamic behavior of a firearm mechanism must be understood to successfully apply Intentional Firearm Microstamping within a firearm. Using a firearm examination technique called “cycle of fire analysis,” Pivotal engineers test firearms and analyze their ejected cartridges. Each cartridge provides an insight into the best surfaces within a firearm to place small Intentional Microstamping elements. Cycle of fire analysis maps the locations where the firearm surfaces actually come in contact with the cartridge under dynamic action. These firearm surfaces are shown in Figure 4 and include, among others, the breech face, firing pin, ejector, breech block, magazine and extractor [14].
For IFM, the primary surface utilized is the firing pin tip. The firing pin tip is used because it is propelled by the hammer during firing and embosses the primer to set off the main charge of the bullet. Since the firing pin hits with great force, it is the best place for stamping the primary code. Further down the firing pin shaft is a second surface that possesses a circular histogram representation of a bar code. A common third surface used by Pivotal is the breech face of the firearm. Referring to Figure 1, in the lower right hand corner, a breech face code can be seen. These three locations have the highest levels of reliability, however various other surfaces can be used and have been identified on tested firearms. Each firearm mechanism is unique and optimization is the process that isolates the best surfaces for IFM’s implementation.

![Figure 4 “Cycle of Fire” Tool Marks and IFM](image)

Once the surfaces within the firearm are identified, a series of optimization tests are conducted. The firearm is outfitted with a matrix of Microstamping features of different geometries and resolutions. As each of these test character sets are cycled through the firearm, a quality level is attached to the resulting features produced on the cartridge surfaces. The data is tabulated and an optimized character set developed. Once the optimized character and feature geometries are chosen they are outfitted into the firearm and it is tested for repeatability of character transfer.

### 2.2 A NATURAL IMPLEMENTATION: THE EASE OF FIREARM ADAPTATION

Over the years, numerous firearms have been tested. Firearms such as: 0.40 Cal SIG P229, 0.40 Cal S&W 4006, 0.22 Cal Ruger Mark III, AR-15 and AK-47, along with many other makes and models have been tested. Figure 5 shows a sample of various Intentional Firearm Microstamping impression examples. Pin impressions pictured are: T. Lizotte’s S&W 4006 0.40 Cal with code “SW10/1233” tested to-date in excess of 6000 rounds; an example taken from this test, a Colt Arms Model 1911 A1 Commander 0.45 Cal., code “C129/A3HJ” fired 1500 rounds; L. Haag’s Glock 9mm, code “GLCK/8463” with approximately 1400 rounds fired; L. Haag’s 30-06 1917 vintage SMG machine gun fired over 1000 rounds; and a rim fire .22LR Cal. Ruger Mark III head stamp shown with code S12/R34 tested to 500 rounds at the time of this picture.
One of the key attributes of Intentional Firearm Microstamping technology is that the protocol for optimizing the code geometry and placement within any style of firearm is a function of the cycle of fire analysis. Many people try to infer a complexity into optimization which does not exist. Optimization is a highly tuned procedural process developed over a 14 year period, designed to zero-in on the microstructures that can deliver the highest statistical probabilities of code extraction certainty. If the mechanism transfers a clear mark, even if it employs a rotary bolt or other exotic bolt system, the optimization protocol isolates the surfaces, locations, and vectors that provide the highest capability of transfer and repeatability.

Even without running the optimization protocol, the experience of developing the protocol allows for better results than traditional unintentional markings. This was demonstrated through the UC Davis testing of an AR-15, where the resulting average transfer rates were high, 88% for alphanumeric characters and 100% for the geometric gear code [15]. The AR-15 test proved to be an excellent example of Intentional Firearm Microstamping because the weapon was not made available for optimization. UC Davis hypothesized that the gas assisted rotary bolt firing mechanism, which operates differently from conventional pistol mechanisms, would pose a problem to the microstructures machined onto the firing pin. It was believed by the UC Davis researchers that a more violent multivariate environment found in the AR-15, would present a far more fatigued microstamp with greater wear and damage. Pivotal engineers leveraged their experience from various other rifles and extrapolated a best guess to create the Firearm Microstamp structures that delivered the above stated results without access to performing a full optimization.

What is unfortunate about the independent testing that has taken place up until now is that the forensic professionals failed to utilize the concept of “integrated data extraction” that mimics crime scene reality. Since traditional matching requires a personal judgment based on years of professional experience, Forensic Toolmark Examiners tend to create self imposed limitations in their analysis methods when looking at features that are truly unique by design. For instance both groups who have reported on Intentional Firearm Microstamping (UC Davis and Krivosta) focused on treating it as a function of the firearm, instead of treating it as “evidence collected at a crime scene.” They built their analysis around a mechanical process with the

Figure 5: Shows a sample of various Microstamping impression examples

Older Model
Handgun
Handgun

Age of Firearms that can be outfitted
Types of Firearms that can be outfitted
All Calibers

New Models
Heavy Machine
Heavy Machine

.22, .25, .380, .45, 5.56 mm, 7.62 mm, 8 mm, .50 etc.
"If it has a firing pin or breach face, it can be outfitted!"
The assumption that at any given moment in time, only one cartridge would be found at a crime scene. Interestingly, this runs counter to the premise used by forensic tool mark examiners during traditional ballistic matching. Traditional forensic matching states that at least 4 or more test fires should be made with firearms recovered at a crime scene to ensure that a suitable sample of cartridge cases is available for matching [16].

When discussing Intentional Firearm Microstamping, it must be remembered that the function of the firearm is not to produce perfect physical evidence. The firearms manufacturers do not design such a function into their guns -- however, Intentional Firearm Microstamping when implemented increases the probability of producing greatly improved physical evidence. The important value found in the UC Davis data is that it reinforced the authors’ general approach that it is always better to implement both alphanumeric and geometric code structures.

This means that some codes will be redundant. It also means that when codes get sacrificed to the unpredictable nature of the violent multivariate firing mechanism, such redundancies will ensure that extractable data is still available by combining information from both redundant code surfaces. In other words, integrated together, the use of both alphanumeric and geometric codes combined will provide exponential opportunities for code extraction. Even in the worse case scenario, as tested by UC Davis when they hypothesized un-optimized microstructure code transfer failures, it was shown that the above described “best-guess” un-optimized characters produced very good results in the AR-15 test.

The biggest difference between the capability of Intentional Firearm Microstamping, which uses intentional tool marks, and that of unintentional tooling marks, is simple – only Intentional Firearm Microstamping focuses on understanding the variables that exist within a firearm tool mark transfer process. Optimizing is what makes Intentional Firearm Microstamping a truly robust technique.

### 3.0 HYPOTHESIS TESTED

During the optimization process, gun mechanics are studied in detail for each model or class of models. Different manufactures utilize different design elements in their frames, slides, firing pin striker mechanisms, safety mechanisms, ejection approaches, etc. The gun chosen for testing in this study is an off-the-shelf Colt Arms Model 1911 A1 Commander, 0.45” caliber ACP semi-automatic handgun.

In the early 1900’s, the U.S. Army called for a larger caliber cartridge in an attempt to suppress attacks during the Philippine-American War. John Browning was one of several gun makers to answer the call by producing the Colt Model 1911. Browning worked closely with Colt employees on the production of his handgun to ensure that it is was of the highest quality. His handgun was chosen as a finalist by the U.S. Army and was put through many rigorous service tests from 1907-1911. Browning’s Colt .45 Automatic pistol, passed the tests easily and on March 29th, 1911 was chosen as the official sidearm of the U.S. Armed Forces and is still used by some U.S. Forces to this day [17]. The design has turned out to be timeless, as it has been adapted and improved upon by countless handgun manufacturers. More then fifty manufacturers produce Model 1911’s worldwide, as well as many variant designs.

The purpose of this test is to implement an optimized firing pin with alphanumeric tip code and a circular geometric gear code surrounding its periphery. At the firing range, a decision was made to shoot 1500
The cartridge cases were retrieved, documented and archived in consecutive serial order for later analysis. During the analysis, only the first four bullets fired from each magazine will be analyzed using IFM code extraction procedures described later. Four rounds are chosen for statistical analysis because, as stated earlier, “cycle of fire” techniques (used for matching a recovered crime gun with evidence) recommend a minimum of four samples, as stated by B. Heard in his book “Handbook of Firearms and Ballistics” [16].

To further validate the premise of extracting codes from the “first four cartridges fired,” it was hypothesized that a typical crime scene where a semi-automatic gun was fired, averaged more than four cartridges from each gun. To test this hypothesis, Pivotal used public data found on the BATF website that promotes the NIBIN program’s “Hits of the Week” webpage [18]. Choosing any recent one year range and averaging the number of cartridges found at the scene, for all available weeks, the data consistently shows that criminalists routinely receive more than 4 cartridges to analyze.

Since this test captured and archived substantially more cartridge case evidence than was used in the analysis published here, additional hypotheses can be developed or refined for future studies. However, for this paper, the following hypotheses were explored based on gun dynamic observations as firing line events unfolded: first round fired, multi-strikes, pin drag degradation and developing an effective quantifiable code extraction methodology.

3.1 DEVELOPING CODE EXTRACTION METHODOLOGY

Quantifying the differences between IFM images in their sequential order of fire leads to the revelation that cartridges collected at a crime scene reproduce their codes as affected by the multivariate forces acting from the moving mechanism. This means that a shot-to-shot variability exists even when the exact same gun fired and ejected the cartridges. The body of evidence might not be large enough yet, or has not been studied with enough detail to reveal each isolated vector influencing the firing process. It does however reveal that when Intentional Firearm Microstamping is used for forensic benefit, a new methodology of analysis is required to ensure (in a statistically quantifiable manner) that the code is extracted with certainty. So not only does the testing procedure need to be far more precise than previous tests, but the code extraction technique needs to be modeled after real world trace evidence collection techniques. Several extraction techniques will be proposed and described in detail after analyzing the collection of cartridges.

3.2 THE SIGNIFICANCE OF THE FIRST ROUND FIRED

Over the last 14 years of Intentional Firearm Microstamping development, the effects of the gun’s dynamic multivariate instabilities have shown themselves to be obvious. Pivotal researchers have observed that the first round fired from a semi-automatic pistol appears to produce better IFM marks than all successive rounds. It can be postulated that the multitude of dynamic variables that affect the firing of a bullet in a gun may be minimized during the firing of the first bullet in a magazine.

The first round, chambered in the breach of the barrel has the benefit of a relatively stress free mechanism surrounding it. The gun, fully loaded, with its safety engaged and holstered, develops its own local equilibrium. When it is drawn and fired, only two mechanical events influence the firing of the bullet: releasing the safety and dropping the hammer to propel the firing pin forward. All subsequent rounds fired are subject to an order of magnitude more force vectors, all of which occur in a newly dynamic state. The
first round fired experiences the most static environment, all the rest of the rounds fired are influenced by stresses and strains acting from multiple directions with varying magnitudes and dynamic interferences.

Observing this first-round-fired microstamping quality, has led these researchers to the adoption of testing procedures that can specifically identify sequentially fired cartridges. It is hoped that a more quantifiable analysis will be possible to confirm that semi-automatic weapons can be shown to produce better cycle of fire results in the first round fired versus all successive rounds that follow.

3.3 FIRING PIN DRAG & MULTI-STRIKES

During the most violent dynamic actions of the pistol cycling, occasional multi-strikes of the firing pin are common. Different gun mechanisms deliver different multi-strike results. With Intentional Firearm Microstamping, not only can the frequency and quantity of the vibrations be recorded, but the actual direction of motion of the cartridge can be quantified. The data in this test will show the manifestations of such multivariate acting forces. It is expected that initial correlations might be made between mechanism causations and the effects observed on the pin impressions. Pin drag, a commonly observable result of gun cycling might be correlated better with above mentioned multi-strike impressions. This test is designed to gather data that can provide a glimpse at correlating the variables that affect gun fire. If nothing else, the data recorded here for the Colt Arms 1911, .45 caliber handgun optimized for this test, can be compared and contrasted with other semi-automatic mechanisms as each type is outfitted with IFM and released to the marketplace.

4.0 TESTING PROCEDURES AND METHODOLOGY

4.1 SERIALIZED CARTRIDGES CAPTURED IN CONSECUTIVE FIRING ORDER

A fundamental premise of the “Scientific Method” requires that data be documented and archived to be made available for careful scrutiny by other scientists, thereby allowing researchers the opportunity to verify results by attempting to reproduce the analysis. Additionally, the “Scientific Method” promotes an ongoing cycle of refining theories. In order to accommodate this, scientists constantly refine their hypotheses leading to a need for developing more useful, accurate and comprehensive testing and analysis methods. Maintaining a serialized archive of cartridges fired, allows a researcher to re-analyze the data as refined methods are created or developed to further the state of IFM understanding.

To facilitate this, Pivotal engineers have implemented a firing range test procedure that captures all of the cartridges fired, retrieved and cataloged in consecutive order. Pivotal uses a storage pallet to help recover the cartridges in order. The pallets are light weight expanded polystyrene foam boards with a matrix array pattern of holes drilled to receive the cartridges in sequential order. Expanded polystyrene foam boards were chosen because the material is very light, yet rigid and is readily available as building insulation found at local hardware stores. When 1500 brass cartridges are assembled for storage, their combined weight in brass alone is already heavy. The polystyrene boards are structurally rigid enough to hold the weight without adding any more than a pound to the entire collection.

Pivotal has chosen to pattern the matrix by 10 columns representing 10 rounds fired from a typical semi-automatic pistol magazine. The majority of common hand guns with the exception of the .45 ACP have 10
round or greater magazine counts. During testing, 10 rounds are loaded even if the magazine holds more rounds. Conforming to 10 cartridges per row provides for easier storage maintenance and downstream analysis. Using ten as the testing interval is convenient for all mainstream guns other than some compact models and the .45 caliber models. The process used by Pivotal requires two separate steps: Capturing the cartridges at the firing range then serializing each one with a permanent and indelible identification number.

4.1.1 Capturing Data at the Firing Range

Capturing the expelled cartridges in exact order requires a little pre-planning and additional manpower to maintain a smooth sequential flow of brass. Setting up a multi-person system to process the steps described below can yield a minimum of 1500 rounds per day. Pivotal recommends the teamwork of four persons to maintain such an optimum schedule.

Step one requires pre-serializing batches of 10 rounds which each magazine will contain. A black permanent marker is used to write the numbers 1 through 10 on the cylindrical surface of each bullet cartridge. It is recommended the number be written adjacent to the extraction groove, where the brass cartridge experiences less expansion during the burn process inside the breech. This will minimize chances of ink loss during the violent brass expansion and cartridge extraction actions a semi-automatic weapon imparts on the brass.

Step two is to load the ink marked bullets into a magazine in reverse order. Bullet number 10 is inserted first and then the rest follow in reverse order. Magazines can be stocked up and pre-positioned for use at the firing line. No additional serialization is required at this point. The magazines can be fired in any order.

Step three entails the actual firing of the gun. Since it is important to model testing which mimics the reality of typical criminal activities, it is recommended that once firing begins, the entire clip is fired off until it is empty. For the purposes of providing physical data to accommodate the hypothesis of the researchers who will be analyzing the data, it is wise to check with them to establish how to trigger pull the contents of the magazine. It is recommended by Pivotal that once the first bullet is fired, all nine remaining bullets be immediately fired off. To ensure consistency, choose a timing interval for firing and stick with it throughout the entire test.

Step four requires that the 10 cartridges fired be captured without losses. Pivotal uses a firing range brass catching net designed for ballistic testing to mitigate losses. Cartridges are retrieved from the net (while the magazine is swapped) and immediately cataloged into the pallet row representing its set of ten cartridges fired in numerical order.

4.1.2 Serializing Cartridges with Indelible Identification

After returning from the firing range, each individual cartridge needs to be laser scribed with a permanent indelible serial number. Pivotal serializes the brass with the date fired and the actual number representing its position in the firing order for the firing pin or breech face being tested. This allows the physical cartridge evidence to be permanently tied to the test, no matter what might happen during future evidence handling events.
Figure 6 shows how Pivotal produces peer-reviewable archive trays, storing cartridges for future evaluation studies. Since each cartridge is captured in sequential order of fire and preserved, future scientists looking to test a new hypothesis or to reproduce the work of predecessors, can continue to access the physical evidence without needing to invest resources to fire more bullets.

5.0 THE POWER OF EXTRACTION

The past 100 years of forensic Firearm and Tool Mark Examination has shown that the unintentional microstamping experienced by the bullet cartridge occurs under a violent multivariate dynamic state of gas pressure expansion during combustion, added to the motion induced during gun fire cycling. The number of variables and their “vectors of influence” (both magnitude and direction) have yet to be experimentally correlated using causation analyses by Firearms Examiners. This poses a major problem for forensic tool mark examiners since the tool marks being observed are unintentional remnants, or what could be termed defects of the manufacturing process. These remnants are neither purposeful nor optimally placed for transferability to the brass cartridge.

For example, with a typical hemispherical tipped firing pin, oscillations of the pin coupled to lateral vibrations imparted into the shell during combustion and slide motion; do not provide the metallurgical resolution capability to detect quantifiable multi strike events. Multiple strikes of the firing pin have gone completely unmeasured and uncharacterized until Intentional Firearm Microstamping structures were added to the tip. For years, Firearms Examiners have routinely discarded suspected multiple strikes while they select out single strike samples suitable for effective forensic matching [16] [2]. However, until Intentional Firearm Microstamping became available, the exact quantity or magnitude of the multiple strikes was never able to be determined with certainty.

Intentional Microstamping structures on the firing pin tip stamp easily-resolvable tool marks into the primer brass, showing the exact count of strikes plus its orientation and their direction of motion during cycling. Some gun mechanisms are highly prone to multi-striking their pin impressions. The multi-strike data described later in this paper shows that the test gun, an off-the-shelf 1911 ACP, double strikes 73% of the
bullets it fires. Other gun designs manufactured to tighter tolerances seem less prone, yet on occasion can clearly print quadruple or quintuple stamps when multiple variables combine to vibrate the firing process.

Figure 7: Multi-Strike Examples (100% extraction)

Figure 7 shows multi-strike examples. Because of the intense violence of combustion, the multivariate acting forces and variability in the cartridge shell’s metallurgy; focusing on the striae formed by Intentional Firearm Microstamping delivers far less value than focusing on extracting the code that those structures represent. The obvious value of extracting the code is that it will provide leads to investigators in real-time who can trace the origin of the crime gun. Later, once prosecutors begin developing a case against perpetrators, traditional Firearm and Tool Mark Examination techniques such as “Cycle of Fire” can be used to make matches from the striae that make up the code. At that point the quality and repeatability of the microstamping structures can be assessed from a traditional examination technique.

Since Intentional Firearm Microstamping can yield trace data as opposed to unintentional microstamping (which assesses quality for the purpose of making matches) physical evidence with such coded structures needs to be analyzed by a methodology geared towards extracting information rather than a traditional matching methodology. By design, a bullet has a primer in the center of its shell or cartridge casing, which is designed using soft ductile brass. The ductility allows a maximum of the kinetic energy delivered by the firing pin striker to be transmitted as a yielding strain to the interior surface of the primer beginning the chemical ignition. Increased ductility manifests itself as a deep firing pin impression and becomes a perfect location for effective intentional striated structure transfer over the largest three dimensional area possible.

In a firearm equipped with Intentional Microstamping each firing pin striker carries an optimized microstructure encoded with serialized codes that identify that individual pin. For redundancy sake, two separate codes are added to every pin. The center of the tip carries an alphanumeric code that can be read directly by examiners. Figure 8 shows the alphanumeric code represented by characters C1 through C8. The second code is found around the outside of the cylindrical area of the pin. It is manifested as a circular variable-pitch gear code read by decoding. This circular gear code is shown as binary digits G1 through G8 separated by the starting wedge.

Both codes impress their striae in different ways, yet simultaneously upon striking the primer. They are designed to react in different ways to the violent multivariate kinetic motion and the various instability vectors acting upon the shell during the cycle of fire. Both codes are designed to be spatially out of phase with each other, ensuring that violent degradations (such as pin drag and smear) which might wipe out certain
characters in one code can provide a high probability of survivability for that character on the other code surface. Reading both codes provides a check against extraction accuracy and the ability to develop a composite score by combining both, in cases when uncertainty encroaches into the extraction results.

By thoughtful design, the process was optimized to deliver high quantifiable code extraction certainties for a single cartridge scenario. However, the probability of full code extraction increases dramatically when two or more cartridges are found at the crime scene. Figure 8 shows an example of double striking, possibly due to pin drag. Such degradations cause information losses or decrease the certainty value of a single cartridge. In the above example, C2, C3 and C4 double struck during the extraction process, yet all the G codes reproduced with a 100% certainty, confirming a complete extraction of information for this one piece of evidence.

5.1 EXTRACTION CERTAINTY

5.1.1 EXAMINER BASED ANALYSIS

Common sense dictates that the alphanumeric code can be read directly, however degradations from the multivariate cycle of fire, its violence and instabilities, require that uncertainty judgments be used to quantify the legibility for each individual character. An Identifiability Score needs to be assigned to each character individually that shows the quality of its legibility. This type of analysis was described by Uchiyama et al. (1988) when studying shot-to-shot variability of cartridge case tool mark striae. Uchiyama assigned three grades of quality to cartridge case striae to describe those that have sufficient features to support a match, those with insufficient features to support a match, or the middle grade for those that fall in between [19].

Since Intentional Firearm Microstamping takes the form of familiar characters like numbers and letters (as opposed to tool mark striae), heuristic means can be employed to identify each individual character. If the character can be read directly with certainty, it would be given a score of one. Any characters that can not be
legibly read because of the gun’s multivariate forces causing a complete wipeout of its structure would be given an Identifiability Score of zero. Partial character structures can continue to be heuristically identified, although the Identifiability Score must correspond with a certainty value (between zero and one) that corresponds with the probability that the character’s partial structure presents enough information to determine it with accuracy.

For example, a smeared letter “A” character may have enough in-tact structure to uniquely identify it as a letter “A,” yet because of the smeared defect; the certainty may only be deduced to a value of 0.75. A letter like “A” has the unique attribute of sharing very little in common with any other character, therefore its uniqueness lends itself to higher certainties and higher Identifiability Scores. Another example might represent how a smeared number “9” would be scored lower because of the orientation of the smearing. A smeared number “9” could be confused with the number “0,” or even a letter “C,” however careful design and optimization of the font structures might limit such confusion. This type of lower certainty can be given an Identifiability Score of 0.50 or lower. Both examples show how lower Identifiability Scores relate to higher uncertainties. Figure 9 shows Code Extraction on a multi-strike cartridge that possesses partial characters due to the gun’s multivariate dynamics causing a partial wipe-out.

The above heuristic identification approach with Identifiability Scoring works best when analyzed by vision analysis software. Such software can facilitate the heuristic character match and based on the area of available un-smeared or multi-strike structure, assign the Identifiability Score in a more precisely quantifiable manner.

**5.1.1 MACHINE VISION BASED ANALYSIS**

Common sense dictates that the alphanumeric code can be read directly, however using a computer based machine vision analysis system can provide greater resolution for determining statistical certainty. One of the key features of Intentional Firearm Microstamping (IFM) is that the code structure is similar by design to a license plate and follows the same types of rules for identification. By standardizing the font size for specific firearm mechanisms and by establishing the area of occupation for each letter, number and symbol, it
becomes easier to utilize off the shelf image recognition or what is called Optical Character Recognition (OCR) software to enhance decoding.

There are six primary algorithms that such software employs for identifying, extracting and quantifying IFM codes:

1. Intentional Firearm Microstamp Code Localization (IFMCL) – responsible for finding and isolating the code on the micrograph relative to landmarks or other features imbedded in the IFM.
2. Intentional Firearm Microstamp Code Orientation and Sizing (IFMCOS) – compensates for the degradations of the IFM code consistent with the firing process and adjusts the dimensions to established code rules.
3. Intentional Firearm Microstamp Normalization (IFMN) – adjusts the brightness, contrast, gamma and other quality attributes of the image.
4. Intentional Firearm Microstamp Character Segmentation (IFMCS) – finds the individual characters on the microstamped cartridge.
5. Intentional Firearm Microstamp Optical Character Recognition (IFMOCR)
6. Intentional Firearm Microstamp Syntactical/Geometrical Analysis (IFMSGA) – analyses character orientations and locations against specific rules governing the caliber and cycle of fire attributes.

Use of OCR is possible and several systems are being evaluated using standard industrial machine vision software and hardware. Typically these off-the-shelf packages run about $3,000 to $4,000 and are easily integrated into existing optical comparison systems. Many are offered as off-line software packages that can analyze micrographs taken from a large variety of laboratory equipment, such as SEM’s, optical microscopes, 3D laser scanning microscopes and con-focal microscopes.

5.2 CODE EXTRACTION METHODOLOGIES

5.2.1 LIZOTTE-OHAR PARTIAL MICROSTAMP CODE EXTRACTION METHOD

Without the use of automated software analysis tools, three intermediate ID Scoring grades have been assigned by Pivotal. This human driven heuristic method of code extraction is known as the “Lizotte-Ohar Partial Microstamp Code Extraction Method.” It extracts quantifiable information in the event of pin smearing and character wipeouts induced by the multivariate firing mechanism using forensic training and a metallurgical optical microscope to make the analysis.

In addition to a perfect score of one or a total character wipeout score of zero, the Lizotte-Ohar Extraction Method sub-divides the scores into three possible values. If the majority of the character is recognizable, regardless of the quantity of the smearing, yet enough to identify it as a single unique character, it is given an Identifiability Score of 0.75. If the character in question represents two or three possible outcomes; the Identifiability Score is given as 0.50. If some character structure is visible, but not enough to narrow it down to three possibilities, then the Identifiability Score of 0.25 is indicated. This human interpreted heuristic partial character method is equivalent to grading the Identifiability Score over five different choices: zero, 0.25, 0.50, 0.75, and one. When extracting codes, each individual character is scored separately prior to tabulating a score for the entire eight digit code or the entire cartridge.

The Lizotte-Ohar Code Extraction Method was developed to extract as much information as possible from Intentional Firearm Microstamping, no matter the resulting impression imperfections subject to the gun’s violent multivariate environment. Such partial codes provide value to investigators and trace evidence specialists while they develop a case or track crime gun movements using COMPSTAT and Geospatial Information System technologies. The value of partial microstamped codes are similar to developing leads
using partial license plate numbers combined with car color or make and model. In this same way, investigators with partial microstamped codes can use caliber, firearm mechanism characteristics, retrieval location and “year of manufacture” to narrow the list of possible guns for investigation and trace.

Partial code extraction is a method that extracts all the information available from a cartridge shell. Using a computer driven microscope based machine vision software system can yield Identifiability Scores to a far finer resolution between zero and one. Using edge enhancement algorithms with a Firearm Examiner driven outlining tool, the examiner can capture any portion of a partially wiped out character (refer to Figure 9). The software driven algorithm then applies blob analysis to determine the total area of the partial character in relationship to its expected available real estate. Next, the computer driven heuristic comparison matches the partial character to a probable character. It also applies a certainty value to the possible match or matches. Both the blob analysis and the heuristic solutions calculate the probability value which determines the final Identifiability Score between zero and one.

5.2.2 Absolute Certainty Microstamp Code Extraction Method

In contrast to the Lizotte-Ohar Method for extracting partial codes to use all available information for the purpose of investigation, Pivotal has developed a second code extraction method which differs by employing “absolute certainty” as a central premise. This approach was inspired by Firearms’ Examiner George Krivosta in his 2006 AFTE Journal report entitled: “NanoTag™ Marking From Another Perspective” [2]. His testing took the perspective of extracting codes using laymen instead of trained forensic professionals to read the pin impressions. In his paper, he postulates that only the characters that can be read with absolute certainty be deemed satisfactory for identification.

Even though common sense dictates that all the available information be considered when extracting Intentional Microstamped codes, using a method that only employs codes that are read with “absolute certainty” provides the advantage of simplicity. The Identifiability Score therefore reverts to just two choices. If the examiner can read the character with certainty, it scores a one. On the other hand, if the examiner determines that any type of unsatisfactory feature interferes with the legibility of any individual character, then its Identifiability Score shall be recorded as zero. Krivosta pointed out that it is common in gun mechanisms to see image degrading effects appear in the pin impression. Most of those effects were discussed above, such as pin drag, smear, lateral vibrations during cycling, etc. These are the randomly occurring multivariate effects that constructively or destructively interfere with the gun’s mechanical function.

5.3 Extracting Alphanumeric Codes

As described in the Machine Vision Based Analysis section above, heuristic identification algorithms are used to analyze the area in which the code characters are expected to be stamped. When it comes to character recognition, heuristics are developed intuitively by humans because it is what is taught in elementary school to children. Heuristic thinking is a cognitive process employed by humans when a solution can not be found using logic. Children learn it as an adaptive strategy to guide them in searching for answers when recognizing letters, numbers and sight words. When characters are missing or wiped out, people learn to apply assumptions to get to the right answer. Heuristic thinking becomes a natural and well practiced skill developed by everyone.
People are vision dominant and the human eye and brain work together to decode pattern recognition. When faced with complete characters, it is easy for people to recognize what is written and we take that for granted. On the other hand, partially smeared or wiped-out characters need to be scrutinized more carefully. Humans do that regularly when trying to read the handwriting of a sloppy writer or a bad speller. The heuristics employed in such a case are typically a very sophisticated series of steps conducted subconsciously in the brain that make a series of assumptions for the un-readable or fragmented letters which then are tested for the probability of the outcome as a whole. People do this type of decoding with very satisfactory results in their daily lives.

A less elegant heuristic method that can be employed to decode the answer to fragmented characters is known as the brute-force search [20]. This method is often implemented in machine vision character recognition algorithms. Humans can employ this method if more time is available or their discipline requires higher certainty. Figure 10 shows example letter fragments and a short list of characters that can be compared directly using brute-force. Using the Lizotte-Ohar Extraction method, an Identifiability Score can be assigned to each fragment. A machine vision system might assign such a score based on the measured blob area of the fragment, divided by the area where the remaining letter was expected to occupy. Increased resolution in the ID Score can be delivered by a machine vision system because it can measure space to a much finer degree as compared to the human judgments found in the Lizotte-Ohar extraction.

![What letter is this?](image)

What letter is this?

![Figure 10: Heuristic analysis of alphanumeric code examples](image)

In the end, criminalists and tool mark examiners can develop a multitude of new methods for extracting probable information that may have been smeared or damaged during the violent multivariate gun firing cycle. Corroborating the possible or probable information extracted from partial IFM codes will always lead to a need for additional more tenacious investigative techniques (refer to section 5.5 for more detail on partial code investigation).

### 5.4 Extracting Circular Gear Codes

Circular gear codes found around the perimeter of the pin impression are best extracted using graphical computer software. Decoding gear codes require a means of measuring in a polar coordinate system. Such measurements are best done by layering angular overlays of gear code digit dividers resembling cuts in a pie.
The overlay should consist of sector lines that radiate from a center point. The first wedge of the pie represents the 24º wide start wedge. These two lines are drawn to radiate 12º from the center point, on either side of the center line (shown as pink in Figure 11). Sector lines that define the 6-bit digital gear characters are drawn in green and represent the remainder of the circular space. These sector lines are positioned around the circle in 42º polar increments. This creates eight sections where character bit information can be found.

![Figure 11: Gear Code Extraction overlay](image)

Shown in the color blue, are radial hash marks placed at 7º increments around the dial. Each 7º space represents a single gear tooth pitch. These blue hash marks, once overlaid, help define the expected gear tooth edges. Refer back to Figure 8 to see how the digital bit spaces created by the hash marks overlay and define the tooth locations.

![Figure 12: Shows a three panel progression that aids in extracting the circular gear code.](image)
Figure 12 shows a three panel progression that can be implemented using an off-the-shelf computer based graphical software such as Adobe Photoshop. The left image is a photo micrograph taken on a high resolution microscope based camera. Using graphical software, the edge of the gear code is traced with a white colored line. The middle panel shows how the angular overlay is positioned in the exact center of the gear code circle and rotated till the start wedge sector lines intersect where it inflects into the circle. By micro positioning the overlay, the hash marks and sector lines split up the polar space to reveal the locations from where the digital information can be extracted.

The third panel shows how the binary digits are extracted. One’s and zero’s positioned in the gear tooth locations help extract the line of text. Notice that question marks have been positioned into an area of uncertainty in the eighth code digit. An interpretation needs to be made using guidelines described in the Lizotte-Ohar Extraction Method (discussed earlier) to determine the certainty value of the extraction.

Any place that you cannot be sure that a gear code edge is visible (perhaps it was smeared during pin drag), is left blank and no bit or digit information is recorded. Such damaged sections must be quantified with an appropriate sub-par Identifiability Score. Further forensic investigative techniques will need to be employed to extract information from inside the damaged areas.

Making the reading from panel three of Figure 12 in a clock-wise direction yields the following digital bar code string:


Numerals one, two and nine are easily identifiable in a recognizable base-two digital numbering system -- the rest of the alphabet follows intuitively. Pivotal leaves out the letters I, O and Q because of their structural similarities to numerals one and zero. Figure 13 illustrates how the gear code histogram resembles a typical bar code with end bar markers.

The original micrograph shows flaws in the extractable image of the alphanumeric code. It is plainly evident that double striking pin smear has effected the pin impression. The Gear Code extraction shows a slight uncertainty in the G8 character where bit two and three are expected to be present. Taking the image of the
Gear Outline that traces these two bits, you can see that a tooth emerges but it is unclear whether it extends to two pitches or just one. Only two possible characters exist for G8. The most probable is a letter J which matches the 6-bit binary code of: 010010. It can be checked and confirmed against the redundant C8 character in the alphanumeric tip code area. Unfortunately, in this example, the C8 character scores a lower numerical certainty value than its G8 counterpart. The only other character that is possible in this G8 location is the letter T which matches the 6-bit binary code of: 011010.

As discussed above, such damaged bits or sections must be quantified with an appropriate sub-par Identifiability Score. Further forensic investigative techniques will need to be employed to extract and confirm the information from inside the damaged area. Ideally, the crime scene evidence collected provides multiple cartridge shells fired by the shooter. Combining and integrating the codes extracted from all the evidence will yield a substantially higher certainty. If this is the only single shot fired by the shooter, other techniques can be utilized to enhance the image such as Scanning Electron Microscopy or laser scanned 3D microscopy. Although, a simpler re-examination of the cartridge in question can be done using different lighting, or the sample can be tilted to more closely examine the actual G8 character edges from a different perspective. Tenacious investigators can come up with multiple ways to increase certainty when critical to solving a crime.

5.5 COMBINING AND CONFIRMING CODES

Gun fire instabilities often produce pin drag or lateral vibrations, causing sections of the code to impress the IFM with smeared out characters or distortions. Extracting individual character codes to assemble an eight digit Intentional Firearm Microstamp may yield a code with missing characters. Characters that can not be extracted should be recorded with a question mark. The same extraction should be done for the circular gear code characters. It too may have sections where the characters are extracted with low certainty values. Refer to Table 1 as a guide for extracting alphanumeric and gear codes along with their corresponding Identifiability Scores.

![Figure 14: An example where composite combination yields very high extraction certainty for round #371](image-url)
Typically, the center tip code and the outer gear code co-exist for redundancy. Both can be used as a confirmation of each other. The circular gear code is laid down around the tip code in an “out-of-phase” manner, increasing the probability that defects induced by pin smear or multi-strikes will produce a very high certainty when the characters are combined and integrated.

Looking at the micrograph in Figure 14, you can see that the pin impression was a single strike; however it smeared across the brass material in what appears to be a faster retracting slide during shell ejection than the retraction speed of the firing pin. Combining both codes together and integrating their ID Scores using the Lizotte-Ohar Partial Extraction Method shows how missing characters in each can be determined with certainty values that are assembled together from each character’s Identifiability Score.

In the above example, pin smearing has wiped out three characters on the tip impression. By plainly reading the alphanumeric code from the micrograph, the two rows can be extracted as: “???9” and “A3HJ.” The top row lost the first few characters with absolute certainty but is capable of delivering partial characters for C2 through C4. However only C4 has enough feature rich value to narrow it down to a numeral “9.” Character C3 appears to be a numeral “2,” but it would take closer forensic scrutiny to eliminate the letter “Z.” So at first glance, this leaves C1 through C3 as un-extractable without deeper investigation by the forensic professional.

On the other hand, notice that the gear code (positioned further down the striker shaft) stamped high quality detectable edges from G1 to G3. Reviewing the extraction results in Table 1 shows how a complete code can be combined using the highest scoring characters from both redundant codes. The missing gear code characters, when combined with the extracted alphanumeric characters deliver a complete code extraction with a 97% certainty value.

| .45 APC test | Alphanumeric Code | Gear Code | Combi Score |
| June 25, 2008 | | | |
| | C | C | C | C | C | C | C | C | C | Ave | G | G | G | Ave | Score |
| ID Score | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | .72 | 1 | 1 | 1 | 0 | 0 | .53 | .97 |

Table 1: Test fire #371 shows how redundant codes combine to deliver 97% extraction certainty

If the examiner were to apply the Absolute Certainty Microstamp Extraction Method as an alternative to test fire #371, zeros would be placed in the ID Scores that did not rank on the level of absolute certainty. Referring to Table 1, you would yield a combination score of 0.88 and an extracted code of C12?A3HJ. Because IFM evidence recovered at a typical crime scene provides high resolution uniquely identifiable character structures (as opposed to unintentional microstamped remnants leftover from a manufacturing process), an examiner using the Absolute Certainty Method must now employ techniques of investigation to drill deeper.

In the same way that detectives do not give up when witnesses provide a partial license plate number on a crime get-away vehicle, Forensic Toolmark Examiners can employ similar investigative techniques to extract that missing C4 and G4 character. The following methods can be applied in whatever order the examiner determines that might lead to the quickest answer: change lighting, focus and magnification to optimize the
region holding C4; employ a tilt stage under the optical microscope to enhance edge detection of the C4 region; increase resolution of the micrograph by sending the sample out for Scanning Electron Microscopy; utilize heuristic matching techniques to assemble a list of all possible character matches to C4; employ traditional “cycle of fire” examination techniques to decrease the list of possibilities; or extract IFM codes from additional cartridges found at the crime scene fired by the same perpetrator.

Tenacious detectives often trace partial license plates by eliminating vehicles off a list of so-called “possibles.” They use additional clues like “type of vehicle.” For example, a witness may have confirmed that they saw a four door sedan. Such a clue can narrow down the list of possible license plates by eliminating trucks, coupes and possibly hatchbacks. Knowing that witnesses said it was dark in color eliminates brightly colored sedans.

In the same ways that detectives whittle down license plates possibilities, forensic professionals can deduce from additional clues enough information to shorten the list of possible IFM numbers. The characters “C” and “A” found with high certainty in positions C1 and C5 signify that Colt Arms manufactured the firearm being tested. Utilizing a trace to review Colt’s firing pin serial numbers and knowing that the cartridge was a .45 caliber may narrow down the list of possible matches. Applying intelligent heuristics to the missing C4 character can help determine that the only probable characters would be 0, 5, 9, S. Notice Figure 15, the number 9 has a sharper more acute inflection (highlighted by the edge trace in the magnified section) in its lower character body area. It can be visibly differentiated from the 5 or the letter S by employing a direct comparison.

![Figure 15: Heuristic brute-force comparison to find the most probable C4 character](image)

Applying higher scrutiny and higher magnification to the region in question provides heuristic methods a greater opportunity to identify the correct answer. Answers from re-analysis combined with information from a trace lead to far higher certainties. Investigative work requires that all possible clues get integrated because it is the clearest way to achieve the correct answer.

### 5.6 EMPLOYING REAL-LIFE CRIME SCENE CIRCUMSTANCES

Mentioned previously, it is important to recognize that typical crime scene evidence delivers multiple cartridge shells fired from a single gun. Common sense requires that firearms examiners extract Intentional Firearm Microstamp codes from all the evidence available and analyze it as a whole. Combining and
integrating all the extractable codes and their respective ID Scores from all the evidence available is an important method for validating certainty. If there are nine cartridges found and confirmed as fired from the same weapon, then nine extractions are combined to deliver a code with a substantially higher certainty. During IFM testing, Pivotal has established a protocol that demands extraction combination and ID scoring integration always be done with the first four bullet cartridges fired from a magazine.

<table>
<thead>
<tr>
<th>.45 APC test</th>
<th>Alphanumeric Code</th>
<th>Gear Code</th>
<th>Combi Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 25, 2008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1041</td>
<td>ID Score</td>
<td>Extract Code</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.50</td>
<td>? ? 2 ? A 3 H J</td>
<td>? ? 2 ? ? ? H J</td>
</tr>
<tr>
<td></td>
<td>Extract Code</td>
<td></td>
<td>C 1 2 9 ? ? H J</td>
</tr>
<tr>
<td></td>
<td>ID Score</td>
<td>.75</td>
<td>1 1 1</td>
</tr>
<tr>
<td></td>
<td>Extract Code</td>
<td>C 1 2 9</td>
<td>.75</td>
</tr>
<tr>
<td>Integrated ID Score</td>
<td>.75</td>
<td>1 1 1 1 1 1 1</td>
<td>.97</td>
</tr>
<tr>
<td>Extracted Integrated Code</td>
<td>C 1 2 9</td>
<td>A 3 H J</td>
<td>C 1 2 9 A 3 H J</td>
</tr>
</tbody>
</table>

Table 2: Test fire # 1041 - 4 shows how real-life crime scene extraction redundancies combine and integrate to deliver 100% certainty

Refer to Table 2 to see how combining and integrating four consecutively fired cartridges can yield dramatically higher certainty values when extracting IFM codes. Developing extraction protocols by mirroring real-life situations shows the power that Intentional Firearm Microstamping delivers to trace evidence consumers.

A quick review of the data extracted from a randomly chosen series of four cartridges shows that when relying on just the alphanumeric code, the violent and randomly functioning multivariate gun mechanism can routinely deliver low overall certainty values. Looking down the columns, it becomes evident that combining and integrating the data, quickly pushes up the identification certainty to a level of 97%. With the gear code set in an out-of-phase relationship, combining data from those columns with the alphanumeric data, very quickly pushes the ID score up to 100% certainty. The above table can be re-written using the Absolute Certainty Extraction Method, but the end result once combined and integrated over the four cartridges analyzed, yields the same 100% result.
5.7 EXTRACTION ADVANTAGES

The ability to extract the code is what makes Intentional Firearm Microstamping such a forceful technique for improving the likelihood that evidence found at a crime scene will yield a direct link to the source of the firearm. The tendency by firearm examiners is to infer that the same issues or limitations found with unintentional tool marks will occur with Intentional Firearm Microstamping.

Such is not the case. When optimizing a specific model of a firearm and its respective mechanism, the testing procedure allows for a complete analysis of the dynamic nature of tool mark transfer in that gun. The fact that Intentional Firearm Microstamped cartridge features can be quantitatively analyzed allows quick and direct analysis of the intentional mark’s “probability of uniqueness.” In either case, IFM is more reliable than unintentional tool mark transfer. Since IFM can be quantitatively analyzed, it offers statistical data that can be directly compared and contrasted with the respective reliability and repeatability of unintentional tool marks. Intentional Firearm Microstamping in its worst-case scenario, for example a 54% transfer rate (when demanding 100% certainty of all the characters, as Krivosha demonstrated [2]; translates into a significantly high probability of >90% extraction rate for the entire code when two or more cartridges are found at the crime scene.

What is perplexing is the thought process described by the firearm examiners who have attempted to evaluate Intentional Firearms Microstamping showing their unwillingness to consider the potential of partial data. In one report, the failure to produce the full 8 digits was considered a failure or unsatisfactory. However, 7 digits still provide a 1 in 40 chance of identifying a firearm. If you then analyze the class characteristics of the cartridge using cycle of fire analysis, you can isolate the firearm even further. The inventors have other means of placing key age identifiers within the code, which will also isolate firearms to a specific manufacturing year. Isolating mechanism groups using cycle of fire analysis, tracing manufacturer databases for code issuing dates, etc.; narrows the gun in question to far less than 40 guns.

![Figure 16: Shows how shifting to higher resolution microscopy helps improve the extraction quality](image)

Failing to comprehend the value and the potential of purposeful codes and geometric shapes imposes limitations on technology that do not exist with Intentional Firearm Microstamping. It is highly unlikely that any investigator has ever given up on pursuing a partial automobile license plate number, especially when they have the color and make of the car as discussed in previous paragraphs. So why conclude that Intentional Firearm Microstamping is a failure when the violent multivariate firing mechanism imparts partial
codes into occasional test samples. For instance, Figure 16 shows how shifting to higher resolution microscopy helps transform what was once termed unsatisfactory into a satisfactory image.

The ease of extracting Intentional Microstamps requires a paradigm shift when compared to traditional firearm and tool mark examination where matching a random scratch on the cartridge evidence, to a random scratch on a test fired cartridge requires years of experience and cultivated judgment. However, Firearm Microstamping is not a technology to replace traditional firearm examination. It is another technique that augments and supports the traditional approach. Intentional Firearm Microstamping is only different because we are all taught how to recognize letters, numbers and geometric shapes from an early age in elementary school and that knowledge and know-how is what drives the extraction process.

6.0 DATA ANALYSIS

As shown in Table 1, the data recorded when using an optical stereo microscope with polarizer/ analyzer metallurgical ring illumination set to full extinction is a reading of the extractable code for each of the 16 digits available in the two code surfaces. A judgment of the Identification Score for each individual character is recorded using the Lizotte-Ohar Extraction criteria outlined in Section 5. Scanning the polarizer to illuminate the brass with scattered light was also done to see the transition of the edge enhancements that such lighting provides.

Of the 1500 bullets fired on June 25, 2008 at the firing line, 1499 brass cartridges were recovered with pin impressions, archived and cataloged for analysis. Bullet #204 jammed during cycling in the Model 1911 pistol and was cleared. All subsequent rounds fired as expected. Firing was never halted for cleaning the gun nor was the firing pin ever serviced or changed. The process began in the morning and continued for over eight hours with one break during lunch. While shooting, it was decided to alternate the firing rate of every other magazine between slow and fast trigger pulls. The first 10 rounds were fired at a rate of one every 2 to 3 seconds. This was considered a typical cycling speed used by shooter trying to attain accuracy on a target. The second 10 rounds were fired at an approximate rate of one every 0.40 seconds. The goal was to squeeze off the trigger as fast as the shooter could fire the gun. Alternating between rapid and slow firing was carried through to the end of the entire data set.

All the judgments for scoring the certainty values for each sample analyzed and recorded were done by the same researcher on the same microscope. Of the 1499 cartridges cataloged, for this paper, 599 cartridge casings were analyzed. From each magazine fired, only the first four consecutive rounds were chosen for analysis, as previously described in Section 5.7. Data point #204 was left blank so that magazine #20 only uses three rounds to complete its analysis.
Identification Scores Analysis

<table>
<thead>
<tr>
<th></th>
<th>Alpha Tip Code</th>
<th>Circular Gear Code</th>
<th>Combination of both Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1st Round Fired</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>.870</td>
<td>.833</td>
<td>.968</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.130</td>
<td>.171</td>
<td>.069</td>
</tr>
<tr>
<td>Variance</td>
<td>.017</td>
<td>.029</td>
<td>.005</td>
</tr>
<tr>
<td><strong>2nd Round Fired</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>.855</td>
<td>.760</td>
<td>.943</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.143</td>
<td>.211</td>
<td>.084</td>
</tr>
<tr>
<td>Variance</td>
<td>.020</td>
<td>.044</td>
<td>.007</td>
</tr>
<tr>
<td><strong>3rd Round Fired</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>.868</td>
<td>.744</td>
<td>.942</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.115</td>
<td>.178</td>
<td>.074</td>
</tr>
<tr>
<td>Variance</td>
<td>.013</td>
<td>.032</td>
<td>.005</td>
</tr>
<tr>
<td><strong>4th Round Fired</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>.901</td>
<td>.815</td>
<td>.969</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.088</td>
<td>.157</td>
<td>.052</td>
</tr>
<tr>
<td>Variance</td>
<td>.007</td>
<td>.025</td>
<td>.003</td>
</tr>
</tbody>
</table>

Table 3: Certainty score statistics for 599 cartridges sampled against firing order

Reviewing Table 3 shows how the cartridge’s mean Identification Score faired in the magazine firing order. It was hoped that the hypothesis postulated over the years that the first round fired out of every magazine produced the highest quality pin impression and IFM. However, the data above shows that when analyzing certainty values while extracting IFM codes that the violent variability characteristics present in all semi-automatic weapons seems to impart variations across all the cartridges, no matter what order they are fired in. However, it would be wise to reduce the next four rounds in the magazine and tabulate the data as a comparison to confirm that the cycling variability continues throughout the rest of the firing order.

**6.1 CODE COMBINATION FOR EACH CARTRIDGE**

The results of combining the two different redundant codes found on each firing pin described in Section 5.6 can be seen in the statistical data found in Table 3. Below are a series of scatter charts that better illustrate the power of code combination and verification. Chart 1 shows 150 first rounds fired in order with extraction certainty scores for both the alpha and gear codes. The alpha codes are represented with triangles and the gear codes use circle markers. The scatter chart reflects the mean ID Score of both individual codes. The lower panel in Chart 1 shows the scatter chart after both redundant codes are combined. For the first round fired, the Combination ID Score improves by 15%.
This is equivalent to collecting a single round at a crime scene and extracting the codes separately as an alpha pin tip code and a geometric gear code around its periphery. When both redundant codes are combined, the certainty of the extraction improves dramatically. Testing each round in the firing order using extraction as the basis for decoding the information delivers identical results. Review Charts 2 through 4 as a comparison.
Chart 2: Second Round Fired Code Extraction Scatter Chart

Chart 3: Third Round Fired Code Extraction Scatter Chart
6.2 FIRST ROUND FIRED

Reviewing the four charts presented in Section 6.1 does indicate that the first round fired appears to have an extraction advantage over the three subsequent rounds. Table 3 presents statistical mean data where round one begins with an apparent 3% advantage over rounds two and three. However, the statistical results of round four contradict the first-round advantage that has been hypothesized. Like all other aspects of the violent multivariate semi-automatic loading mechanism, it appears that the random nature of so many simultaneous acting variable or mechanical vectors can be seen in this data. To further prove or disprove the first round advantage, further data is required. The next 600 rounds fired in this test should be extracted to compare to this data. Because the archive holds 1500 rounds, another 300 rounds are available after that point.

Since Table 3 seems to show that random effects from the multivariate mechanics driven by constructive and destructive interference have a greater influence on IFM extraction certainty values, scatter charts were chosen to help see into such stochastic results. Reviewing the Combination Score panels in each of the four charts shown in Section 6.1, continues to show the advantage experienced by the first round fired. Scatter charting graphically display the aspects of what the simple statistical calculations can not convey.

The interesting two results that can be taken from comparing the scatter charts is that randomness does exist, yet it always converges towards 100% certainty. Secondly, the combined score panel for the first round does show graphically that an advantage exists when compared to the combined score panel for the fourth round.
All the scatter chart panels, regardless of firing order, show that code extraction techniques statistically converge toward certainty values of 100%. Consider the multivariate actions that happen in the following order once the shooter pulls the trigger: the hammer fall, the firing pin strike, the chemical ignition of the bullet’s propellant, the instantaneous gas pressure rise, the recoiling motion of the firing pin, the recoiling motion of the mass of the slide, the change in weapon recoil motion once the projectile exits the barrel and the deflagrant gases begin to escape, the unlocking of the barrel, the rearward and downward motion of the cartridge case [25], the forces of the next bullet in the magazine pushing up, the ejector colliding with the cartridge imparting a radical change in its motion vector, the re-cocking of the hammer, a 180 degree change in slide motion, the upward motion of the next bullet entering the breech changing to a forward motion when contacting the breech face, the slamming of the breech, the engagement of the extractor, the locking of the barrel. Yet in that process, each discrete motion begins in the serial order stated, but the timing interval that each step takes to finish is independent and non-deterministic. Previous steps continue to overlap the beginning of the next step, or even worse, to overlap several successively beginning steps. Add in mechanical interferences, resistances and impedances, and it is no wonder that such a stochastic process emerges to influence the firing of a semi-automatic firearm. On the other hand, even though firing the gun can be shown to be stochastic, the process of IFM code extraction constantly shows a convergence toward predictable outcomes with very high statistical certainties.

In conclusion, there appears to be a slight first round advantage. Quantifying it will require better analysis methods and reducing the additional cartridge data not yet extracted from the remaining rounds. Comparing this data to data taken in the same way while testing guns designed and produced by other manufacturers will further help prove or disprove what these researchers have observed empirically while creating optimization procedures for implementing Intentional Firearm Microstamping, as well as seeing the scatter chart data presented above.

6.3 INTEGRATING CARTRIDGES FOUND AT A CRIME SCENE

Crime scene reconstruction methodologies are appropriate when considering real life situations where the use of physical evidence created by IFM will be analyzed. Firearms are not designed to produce perfect evidence, so every feature provided by the evidence found at a crime scene needs to be considered both separately and as a whole. According to the Association for Crime Scene Reconstruction, the definition for Crime Scene Reconstruction is: “The use of scientific methods, physical evidence, deductive reasoning, and their interrelationships to gain explicit knowledge of the series of events that surround the commission of a crime.” The combination or integration of evidence is not a unique technique. Many times all the cartridges at a crime scene will be evaluated against a recovered firearm’s test fired cartridges.

The approach by the authors of this paper was not to look at all 1500 round test samples as a sequential series of cartridges. Instead, the approach was to analyze each time a magazine was fired, testing the firearm in terms of 150 separate criminal incidents (10 rounds per magazine). In the real world, the firearm is brought to a crime scene with at least one magazine of bullets. By establishing the experiment for a real life scenario, it demonstrates the real life performance of the physical evidence as a forensic tool, rather than just testing the physical wear characteristics of firing pins over time.

Analysis of 1500 rounds sequentially yields nothing that can be interpreted as useful data for evaluating forensic benefit. Since the gun’s firing cycle is a stochastic process, and by conceding this obvious fact up front, the authors targeted the periodic nature of an actual crime scene event and focused on the individual
magazines and the sequential cartridges in the firing order that actually affect the probability of code extraction. This approach provides a far better understanding of the forensic benefit as well as a real life performance evaluation of IFM and its methods of code extraction. IFM delivers its value by implementing tests that focuses on “one firearm, one magazine,” combined and integrated into one high certainty code extracted and verified with redundancy.

Since IFM extraction was meant to mimic real crime scene evidence collection, the extracted data will be shown below in sets of four consecutive rounds fired. As described in Section 5, this type of approach shows how code extraction exponentially increases the certainty value of the evidence being analyzed. By combining redundancies from each pin impression then integrating the information extracted from each additional cartridge collected at the scene, extraction certainty quickly converges towards 100%.

### Integrated Identification Scores

<table>
<thead>
<tr>
<th>Combination Score Statistics</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.9683</td>
<td>.0686</td>
<td>.0047</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrated Score Rounds 1 &amp; 2</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.9923</td>
<td>.0280</td>
<td>.000786</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrated Score Rounds 1, 2 &amp; 3</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.9981</td>
<td>.0104</td>
<td>.000108</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrated Score Rounds 1, 2, 3 &amp; 4</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.9994</td>
<td>.0077</td>
<td>.000059</td>
</tr>
</tbody>
</table>

Table 4: integrated certainty score statistics for rounds fired in sequential order per magazine

Table 4 shows the statistical improvements as certainty values achieve two-nines quality when two cartridges are integrated. Additional rises in quality can be progressively seen as the convergence continues. Four cartridges achieve three-nines in this 599 cartridge analysis as it is broken down to mimic evidence collected at a crime scene. The analysis is tabulated using the 150 round subsets described earlier.

Below Chart 5 graphically shows the convergence and the dampening of the variability as more information is utilized for the extraction of the crime gun codes through multi-cartridge integration.
Chart 5: Integrated Code Extraction Scatter Chart showing a 4 round progression
The progression demonstrates how close to 100% the certainty values converge once enough data has been collected. Amazingly, the average number of cartridges collected into evidence at typical semi-automatic gun crimes has been pointed out to be in excess of four.

To explore how significantly multi-cartridge integration affects the individual crime scene scenario, a handful of the worst extraction scores were chosen for detailed review. The table series below show pin impressions decoded utilizing the Lizotte-Ohar Extraction Method. Table 5 begins with the first four cartridges fired from magazine #1. It ends with the results of the last magazine fired. All the extractions shown in between represent data selected from the worst performing pin impressions.

<table>
<thead>
<tr>
<th>ID</th>
<th>.45 APC test</th>
<th>Alphanumeric Code</th>
<th>Gear Code</th>
<th>Combi Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID Score</td>
<td>← ← ← 1 .75 .75 .75 .81 ← ← ← ← ← t .94 .94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>002</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>ID Score</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extract Code</td>
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<td>C 1 2 9 A 3 H J</td>
<td>C129 A3HJ</td>
</tr>
<tr>
<td></td>
<td>003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID Score</td>
<td>← ← ← 1 ← 1 .50 .94 ← .50 ← ← 1 .75 ← ← .66 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ID Score</td>
<td>← ← ← 75 ← ← 1 0 .84 ← .50 ← .50 ← ← ← ← .75 .97</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integrated ID Score</td>
<td>← ← ← ← ← ← ← ← ← ← .94 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>C 1 2 9 A 3 H J</td>
<td>C129 A3HJ</td>
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</table>

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<table>
<thead>
<tr>
<th>.45 APC test</th>
<th>Alphanumeric Code</th>
<th>Gear Code</th>
<th>Combi Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 25, 2008</td>
<td>C1  C2  C3  C4  C5  C6  C7  C8  C ave</td>
<td>G1  G2  G3  G4  G5  G6  G7  G8  G ave</td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>ID Score</td>
<td>75  1  1  25  50  50  0  0  .50</td>
<td>1  75  1  75  75  75  75  75  .53</td>
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<tr>
<td>242</td>
<td>ID Score</td>
<td>1  1  1  1  75  1  1  75  1.0</td>
<td>1  75  1  75  75  75  75  75  .50</td>
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<tr>
<td>243</td>
<td>ID Score</td>
<td>1  1  1  25  1  75  1  75  .94</td>
<td>75  50  50  75  1  75  1  75  .81</td>
</tr>
<tr>
<td>244</td>
<td>ID Score</td>
<td>1  1  1  25  1  75  1  75  .84</td>
<td>50  0  0  75  1  75  1  75  .66</td>
</tr>
</tbody>
</table>

**Integrated ID Score**

1 1 1 1 1 1 1 1 1.0

**Extracted Integrated Code**

C 1 2 9 A 3 H J  C129 A3HJ

---

<table>
<thead>
<tr>
<th>.45 APC test</th>
<th>Alphanumeric Code</th>
<th>Gear Code</th>
<th>Combi Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 25, 2008</td>
<td>C1  C2  C3  C4  C5  C6  C7  C8  C ave</td>
<td>G1  G2  G3  G4  G5  G6  G7  G8  G ave</td>
<td></td>
</tr>
<tr>
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<td>ID Score</td>
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<td>1  1  1  75  .25  0  50  75  .75</td>
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<tr>
<td>412</td>
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<td>25  1  50  25  0  50  25  0  .47</td>
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<tr>
<td>413</td>
<td>ID Score</td>
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<tr>
<td>414</td>
<td>ID Score</td>
<td>1  1  1  75  50  50  50  .78</td>
<td>1  1  50  50  50  50  50  .69</td>
</tr>
</tbody>
</table>

**Integrated ID Score**

1 1 1 1 1 1 1 1 1.0

**Extracted Integrated Code**

C 1 2 9 A 3 H J  C129 A3HJ

---

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### 45 APC test
### June 25, 2008

<table>
<thead>
<tr>
<th>ID</th>
<th>Score</th>
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<th>ID</th>
<th>Score</th>
<th>Extract Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>461</td>
<td>25</td>
<td>? 1 2 9 A ? ? J</td>
<td>50</td>
<td>1 1 1 ? 1 0</td>
<td>? 1 2 9 A 3 H ?</td>
</tr>
<tr>
<td>462</td>
<td>1</td>
<td>C 1 2 9 ? ? ? ?</td>
<td>75</td>
<td>.75</td>
<td>C 1 2 9 A 3 H J</td>
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<tr>
<td>463</td>
<td>1</td>
<td>C 1 2 9 ? ? ? ?</td>
<td>75</td>
<td>.75</td>
<td>C 1 2 9 A 3 H J</td>
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<tr>
<td>464</td>
<td>1</td>
<td>C 1 2 9 ? ? ? ?</td>
<td>75</td>
<td>.75</td>
<td>C 1 2 9 A 3 H J</td>
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</table>

### Integrated ID Score
1 1 1 1 1 1 1 1

### Extracted Integrated Code
C 1 2 9 A 3 H J

### .45 APC test
### June 25, 2008

<table>
<thead>
<tr>
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<th>ID</th>
<th>Score</th>
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<th>Score</th>
<th>Extract Code</th>
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### Integrated ID Score
1 1 1 1 1 1 1 1

### Extracted Integrated Code
C 1 2 9 A 3 H J

---

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<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1381</td>
<td>25 0 50 1 25 50 1 .56</td>
<td>1382</td>
<td>1 1 1 1 1 1 1 1 1.0</td>
<td>1383</td>
<td>75 1 75 1 75 75 1 .88</td>
<td>1384</td>
<td>75 1 75 1 75 75 1 .84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrated ID Score</th>
<th>Extracted Integrated Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>C 1 2 9 A 3 H J</td>
</tr>
</tbody>
</table>

Table 5: Seven panels above showing Integrated Code Extraction using the Lizotte-Ohar Partial Code Extraction Method; notice magazine #1, magazine #149 and a selection of the worst scoring magazines in between.
Notice that cartridges #471 through #474 represent the only series of four cartridges that did not extract a full eight digit code in the entire test. Referring to Chart 5, magazine 47 (or crime scene 47) on the scatter chart, it can be seen as the lone data point that scored an Integrated ID Score of 0.91. All other consecutive four cartridge sets of data when integrated over the first four cartridges fired from each magazine, scored certainty values of 1.00.

If the above dataset had been presented with IFM code extractions using only the Absolute Certainty Extraction Method, where only “zeros” and perfect scores of “one” get recorded for each individual code digit, the success of extraction would have been the same. Of the 150 magazine sets of four cartridges analyzed, 149 would have extracted and confirmed the correct code at 100% certainty. Magazine #47 which delivered a score of 0.91 and failed to extract digit #6 would have dropped to a score of 0.88, but it would have delivered the identical seven out of eight digits. The more significant aspect of combining and integrating extracted codes allows forensic professionals the freedom of using a quick analysis method such as Absolute Certainty Code Extraction when beginning a case. What is shown in this data is that Absolute Certainty Methods would have delivered quick, accurate answers for investigators to pursue with 100% certainty in 99 out of 100 incidents at a crime scene when a minimum of four cartridges are collected into evidence. This leaves the use of partial code extraction as a second tier analysis method that only needs to be applied to those few occurrences when the answer can not be determined through the use of Absolute Certainty IFM Code Extraction.

### 6.4 MULTIVARIATE DEGRADATION SEEN AS MULTI STRIKES & PIN DRAG

While extracting codes and recording ID Scores for each of the 599 cartridges analyzed, two additional pieces of data were recorded for each cartridge: the number of multi strikes and the existence of pin dragging that might cause smearing. Both phenomenon are well known and have been written about in the forensic literature. Pin vibration and multi strikes have been suspected but not quantifiable until IFM [2].

Pin drag has always been easy to identify. Its degrading effects are often seen as smearing of the primer brass. Depending on the microsecond in time that the pin’s late retraction dragged across the cartridge during the gun mechanism cycling, portions of the IFM code can smear and become degraded. For the purpose of this paper, the magnitude of the smeared degradation was not quantified. While analyzing this dataset, it was observed that at times small pin drag affects damaged the extraction certainty, yet at other times it did not. Such observations further support the stochastic nature of the gun firing and cycling process. In the future a separate study can be developed to quantify the smearing magnitudes. The purpose of collecting pin drag effects for the Model 1911 was to help understand how often the multivariate actions of the mechanism coalesce to produce recognizable defects on the cartridge.

It was not the intent of this paper to classify or quantify the degradation, only to tabulate the occurrences. The Colt Arms Model 1911 used in this test showed a 69.8% occurrence of pin drag. Pin drag appears to be a phenomenon seen when the gun mechanism begins cycling after ignition of the bullet, when the firing pin still continues to have forward moving energy. The cause of drag might manifest itself in the form of lateral vibrations slowing down pin retraction, or it might happen when the firing pin experiences multiple forward propelling forces. The nature of how or why it occurs can be varied and multiple because the mechanism is
influenced by so many destructive and constructive multivariate interfering forces. The fact that it occurs can be clearly seen and studied in the collected archive of cartridges.

It must also be noted that the geometric structures on the tip of the pin enhance the ability to recognize pin smear that occurs at a smaller magnitude. So in the past, minor dragging that occurred inside the pin impression may have been gone unnoticed. The embossing of the IFM features provides something other than a smooth hemispherical tip making smearing far easier to recognize.

In the same way firing pin multi-strikes are clearly related to pin drag, although until IFM became available, identifying and counting multi-strikes in the cartridge impression has been very difficult. Reviewing the data collected for the 599 cartridges sampled here, the Model 1911 struck double pin impressions 54.8% of the time. Further review of the data shows that a single pin strike with no visible drag marks only occurred on 13.9% of the samples tested. Therefore 86% of the cartridges showed some type of degradation induced by the stochastic process of firing and cycling the pistol. Yet the data shows that code extraction continued to be possible with a very high statistical certainty.

As a side note, one cartridge showed a triple strike and one showed a quadruple strike which can be seen in Figure 9 as two powerful strikes with an additional vibration. While optimizing other gun models, multi striking effects were observed much less frequently than the Colt Arms Model 1911 chosen for this test. To see photo micrographs of the degradation brought on by multi-strikes and pin drag, review the figures in Section 6.5.

6.5 OVERCOMING MULTIVARIATE DEGREDATION

In the late sixties and early seventies there was considerable work done on the benefits of Scanning Electron Microscopy (SEM) for the analysis of firearm evidence found at crime scenes. Nearly 40 years have past and the initial arguments of cost and convenience back in 1969 are no longer an issue today. With 40 years of commercial availability, SEM tools are more common and easily accessible. In many states, SEM services through contract SEM job-shops are available on a price-per-hour basis, allowing greater ease of access to the technology.

Over the years, there have been articles that showed glimmers of hope that SEM would be reconsidered as a tool for firearm examinations. One such article published in the ATFE journal in 1992 [Mann, et al] titled, “Firearms Examinations By Scanning Electron Microscopy,” emphasized that the benefits are significant enough to consider the use of the SEM as a tool in cases where: bullets, jackets or cartridges are seriously damaged, the comparable surface area is reduced, or the striae detail is too shallow for optical examinations [22] [23]. The authors of this article went as far as to clearly state they observed that scanning electron microscopy has significant advantages over conventional optical comparison microscopy in such cases.

Whenever conducting IFM testing or analysis at Pivotal Development, it is common to isolate those few pin impressions that were found to be damaged with smearing and multi-strikes, by the violent multivariate firing process. SEM images not only deliver a higher resolution to their micrographs, but they posses two characteristics that are very difficult to control with traditional optical microscopy. The first is illumination control. Metallurgical surfaces are difficult to illuminate because the material is so highly reflective causing oversaturation and localized blooming with visible light. Secondly, optical microscopy suffers from reduced depths of focus as magnification increases. Scanning Electron Microscopy is affected by neither. It provides
a high degree of illumination control over metal surfaces and has no image focus limitations. Figures 17, 18 and 19 are examples of how the use of SEM for isolated incidents can yield higher extractable certainty and more information. The optical micrograph is shown on the left for comparison.

![Figure 17: Test fire #841 Optical on the left, Back-Scatter SEM to the right with software enhanced extraction](image1)

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<th>.45 APC test</th>
<th>Alphanumeric Code</th>
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Table 6: Test fire #841 comparison between SEM and Optical micrograph

Figure 17 and 19 were imaged in the Scanning Electron Microscope using the back scatter imaging approach. Optimizing the back scatter feature often delivers a truer looking image when sampling metallurgical samples. Figure 18 is an example of the standard micrograph that the SEM delivers, notice that it highlights sharp vertical edge transitions. Soft brass is a very malleable metal which galls easily when deformed. Both sharp vertical edges, as well as rolled over impressed features are formed in the pin impressions -- it is preferable to look at both types of images while evaluating extractable IFM codes.

![Figure 18: Test fire #1141 Optical on the left, standard SEM to the right with software enhanced extraction](image2)
### Table 7: Test fire #1141 comparison between SEM and Optical micrograph

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Table 8: Test fire #1441 comparison between SEM and Optical micrograph

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Figure 19: Test fire #1441 Optical on the left, Back-Scatter SEM to the right with software enhanced extraction.
7.0 CONCLUSIONS

Data presented in this paper clearly shows that the randomness of a firearm’s stochastic working action, driven by its multivariate forces, creates the degraded pin impressions shown here as typical. Such degradations have been suspected by the forensic community for years, but without Intentional Firearm Microstamping’s unique geometric structures, the pin impressions could not be statistically quantified nor could correlations be made pointing to the forces and their vectors causing the effects. It can be seen that the mechanical process responds with random behaviors that are presented as randomly varying pin drag and multi-directional vibrations. Stochastic processes, being non-deterministic in nature, require analysis by statistically probabilistic analyses; however IFM when studied from a real-world implementation perspective, using code extraction, has the advantage of showing convergence towards 100% certainty. Given enough data, given enough recoverable cartridge cases, the statistical certainty of IFM code extraction quickly approaches 100%.

The reason IFM performs so well is because it is matched to the dynamic behavior of the firearm mechanism when implemented. This paper clearly identified the fact that with an intentional mark, by design the IFM becomes a forensic method for tracing guns that has the robustness similar to such forensic method as DNA analysis. By providing a consistent and high degree of certainty, IFM is the only forensic tool that provides a physical evidence “link between firearm evidence (e.g. the fired cartridges found at a crime scene) and a specific firearm source.” IFM codes can be extracted quickly and used without the need to recover the firearm. Furthermore, through the process of extraction, IFM codes can be quantitatively verified to a higher level of certainty as compared to traditional forensic matching techniques.

In a recent Supreme Court decision, Melendez-Diaz vs. Massachusetts, Justice Anthony Scalia offered the courts opinion referencing the finding in a National Academy Study report (page 15) [1]. Justice Scalia emphasized that the NAS stated that, “There is wide variability across forensic science disciplines with regard to techniques, methodologies, reliability, types and numbers of potential errors, research, general acceptability, and published material.” He highlights the NAS report offering, “problems of subjectivity, bias and unreliability of common forensic tests such as latent fingerprint analysis, pattern/impression analysis, and toolmark and firearms analysis” [1] as problems needing to be rectified.

This decision opens the door for defense attorneys to cross examine forensic professionals and in light of the National Research Councils, National Academy of Science Report summation that, “Forensic evidence is often offered in criminal prosecutions and civil litigations to support conclusions about individualization -- in other words, to "match" a piece of evidence to a particular person, weapon, or other source. But with the exception of nuclear DNA analysis, the report says, no forensic method has been rigorously shown able to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source [1]. The fate of firearm and toolmark identification is clearly at risk. This further reduces the tools available for prosecutors to convict criminals. However, Intentional Firearm Microstamping can play a vital role if it is embraced by the forensic community.

IFM lends itself to be leveraged in support of the existing methods of firearm and toolmark identification. The creation of an intentional toolmark creates an archetype toolmark that is unique and quantifiable, and it can be shown to be quantifiable to a high level of statistical certainty. IFM could be classified as a “Class Mark” which is by definition, quantifiably unique. Current sub-class toolmarks can then be attributed to this
uniquely identified firearm. Such is the goal of IFM, to support existing methods of firearm and toolmark identification and leverage the existing network of firearm and toolmark examiners and forensic professionals that already work in this field.

Threats are not always visible; however intelligence gathered by identification of firearms that are not recovered can effectively counter such threats. Having this type of intelligence can constitute a powerful and effective firearm trafficking mitigation tool. The world is more complicated and the deficiencies of the old way of investigating have long been identified. There must be a push for the evolution of investigative methods to balance objectivity and efficiency; however it must be supported with technology that can deliver results with a high statistical certainty. It has been stated that a change in attitude is needed in order to accept an extended role for forensic science that goes beyond the production of evidence for the court [24]. This new role looks at evidence from the viewpoint of forensic intelligence but still offers prosecutors unassailable evidence to convict criminals along the way.

8.0 REFERENCES

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