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Occurrence and Utility of Latent Print Correspondences that are Insufficient for Identification

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Abstract

Latent prints that have insufficient characteristics for identification often have discernable characteristics that could form the basis for lesser degrees of correspondence or probability of occurrence within a population. Currently, those latent prints that experts judge to be insufficient for identification are not used as associative evidence. How often do such prints occur? What is their potential value for association? Would they actually impact case investigations or prosecutions in a useful way? The answers are important. We could be routinely setting aside a very important source of associative evidence, with high potential impact, in many cases; or such prints may be of very low utility, adding very little, or only very rarely contributing to cases in a meaningful way. This project provides substantive answers to these questions.

Non-identifiable fingermarks (NIFMs) from casework were collected from nine jurisdictions within the USA. These prints had fallen below the expert-determined threshold “of value for identification,” but had some clear Level 2 detail (3 or more minutiae) within an area of contiguous ridge flow. Expected score-based likelihood ratios (ESLRs) were measured based on modeling within-variability and between-variability of AFIS scores. This method incorporated (1) latest generation feature extraction, (2) a (minutiae-only) matcher, (3) validated distortion functions, and (4) NIST SD27 database calibration.

A total of 1668 fingermark images, representing 890 cases, were collected. Screening to remove potentially identifiable prints and those with less than three minutiae left 750 NIFMs. Expected associative values for these NIFMs showed mean value of Log_{10} ESLR of 5.56 (s.d. 2.29), corresponding to an ESLR of approximately 380,000. That is, the strength of association would be the same as for an event occurring one time in 380,000. The results show that NIFMs commonly occur and that they offer the prospect of strong associative evidence.

These results were summarized and explained to a broad audience of criminal justice participants and stakeholders, obtaining individual reactions, including views on the potential contribution, issues that would affect this contribution, approaches to development, and areas of concern.

NIFM evidence was found to be clearly distinct from conventional fingerprint evidence, and exceptional among less definitive classes of evidence. NIFMs are already routinely and inexpensively collected, they can be objectively evaluated, they occur very frequently in cases, and they occur multiple times in each case. They are comparable to many eyewitnesses in one case, each with a measurable credibility, testifying as to what was touched and by whom.

NIFM evidence was found to be material. It can support or refute the identity of a person touching a surface, provide evidence supporting the identity of a person present at a location, and provide evidence supporting involvement of an individual in an activity. It can combine with other facts in a case to show when a surface was touched, or to improve or diminish the credibility of other evidence.

A wide range of potential contributions were revealed at different levels in the criminal justice process, including aiding in criminal investigations, forensic analysis and investigative decisions; aiding prosecutorial decisions pre-trial; providing evidence at trial; in post-conviction reviews

and in special investigations: high profile critical incidents, cold case investigations, serial crimes and gang activity. Overall, there is a high potential impact from a frequently occurring type of physical evidence, which will require minimal additional effort to implement.

Some areas of application are suitable for immediate use. Other areas will require further development or research in the methodologies, and still others require developments in forensic science as a whole. Significant issues for the implementation of NIFM evidence are: vetting of measurement methods; concurrent development of methods showing NIFM support for and against associations with a given individual; providing timely findings to enable investigative applications; allocation of resources commensurate with utility; and education of participants in the capabilities and limitations of the methods. Other areas of general forensic science concern are: implementation in the laboratory with appropriate quality assurance and reporting thresholds; communication of probabilistic measurements of the weight of associative evidence; and the potential misuse of non-definitive associations by law-enforcement or prosecutors during investigations, arrests, and charging.

Areas for reasonable follow-on research have been identified. The next steps in moving toward in the implementation of NIFM evidence are (1) exploring the actual value of NIFM associations in investigations, (2) further development of measurement methods for NIFM associations, (3) development of processes for searching NIFMs among small groups of individuals, and (4) testing the usefulness of NIFM evidence as part of post-conviction reviews.

In anticipation of the future application of NIFM evaluations to evidence, it is important that latent fingerprint records be retained, even if they do not show latent prints that are considered identifiable or comparable by current practices. Furthermore, latent fingerprint collection practices should be revisited to ensure that the smaller, more abundant NIFMs are recovered and retained during crime scene and laboratory fingerprint processing, especially when they are present in material locations.

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I. Introduction

Current fingerprint examination practices only result in associations when there is an identification. This is a very high threshold of associative value, with nearly negligible rates of false association when appropriate expert qualifications and laboratory controls are in place. However, this leaves many smaller non-identifiable fingermarks (NIFMs) unused. These marks often have discernable characteristics that could form the basis for lesser degrees of correspondence or probability of occurrence within a population. How often do such NIFMs occur? What is their potential value for association? Would they provide significant useful information to investigators, prosecutors and courts?

The answers are important. We could be routinely setting aside a very important source of associative evidence, with high potential impact, in many cases; or such prints may be of very low utility, adding very little, or only very rarely contributing to cases in a meaningful way.

At the same time, there are significant challenges to unlocking this potential. Until only recently,[1] a central aspect of fingerprint examination was the restriction of conclusions and testimony to categorical, absolute identifications, or inconclusive.[2-4] In the absence of alternatives, this all-or-nothing approach has been an effective, though imperfect compromise.[5] Methods to measure the associative value (selectivity) of fingerprints are currently under active development,[6-14] but are not yet sufficiently defined and vetted for widespread use and acceptance. However, we can be sure that such methods will not be long in coming.

A second difficulty is that the recovery and examination of NIFMs, and the use of statistical models to interpret them, will require the support of fingerprint practitioners and the courts.[15] A paradigm change is necessary from the current methodology and conclusion scheme, and related training, changes in operation and changes in reporting will be necessary.

It would take considerable effort to change these processes. Should this be our priority? New technologies offer a wide range of capabilities for latent print examinations,[16] with expected improvements in documentation, reproducibility of results, quality assurance, and efficiency. Is the potential contribution of NIFMs to investigations, prosecutions and post-conviction reviews sufficiently high that resources should be committed to work toward these changes?

We currently don't know. Prior to this work there has been only minimal information regarding the application of probability models to study NIFMs[15] and no information that is based on either (1) currently available technologies or (2) the utility NIFMs in context of where and how they actually occurred in the case.

This goal of this project was to address these knowledge gaps by (1) making reasonable measurements of the occurrence and associative value of non-identifiable fingermarks, and (2) given these results, assessing the criminal justice utility of latent print correspondences that are insufficient for identification. This information provides a factual basis to set the priority for development and validation of methods to exploit the use and associative value of NIFMs.

II. Part 1 - Occurrence and Associative Value

II. A. Overview and Objectives (Part 1)

The purpose of Part 1 of this project was to explore and test a theory that in large numbers of cases fingermarks of no value for identification occur and are readily available, though not used, and yet have associative value that could provide useful information.

NIFMs from casework were collected from nine jurisdictions within the USA. These prints had fallen below the expert-determined threshold "of value for identification," but had some clear Level 2 detail (i.e. minutiae) within an area of contiguous ridge flow. An expected associative value (selectivity) of each of these marks was measured (without reference to a putative source) using an AFIS-score model. Whether an AFIS-score based system is the best option to assign the weight to latent print evidence is currently debated,[9,17-19] but regardless of their ultimate suitability for that application, these systems can be validated and calibrated,[20] in a way that allows a means to explore and quantify the potential of using latent prints that are currently left aside in operational practice.

The expected associative values of the NIFMs were categorized by type of crime (violent crimes vs. property crimes) and objective measures of latent print quality.[21-23] Testing for differences among crime categories was of interest because of the possibility that alternative practices such as the extent of crime scene processing or the retention of fingermarks, could result in differences in the distributions of associative value among the NIFMs. Latent print quality measures are of interest as they may be highly correlated with associative value.

II. B. Methodology (Part 1)

II. B. 1. Collection of Non-Identifiable Fingermarks

Fingermarks (latent prints) were collected from casework produced using existing investigative procedures within the particular jurisdiction. Fingerprints had previously been analyzed by expert latent print practitioners to be of "no value for identification" (NVID), but contained some well-defined minutiae in areas with continuity of ridge flow.

To be reasonably representative, marks were collected from nine different jurisdictions within the USA. This variety is important to provide a reasonable overall view because it is known that judgements of NVID will vary with the individual expert,[23] and it is expected that specific laboratory policies or crime scene investigator practices could influence how latent prints are collected and examined. Our research need was for a reasonable cross-section of current practices that would (1) provide a realistic breadth of clarity and quality among the qualifying NIFMs, and (2) ensure that the results are meaningful across a range of jurisdictions and practices.

Qualifying NIFMs for this study needed to show three or more clear and reliable minutiae occurring within an area showing continuity of ridge flow. This quantity of ridge detail was selected as a lower bound representing a rational minimum to be considered.

High quality images [24] of NIFMs meeting these criteria were collected from each jurisdiction, retaining only the latent image itself and the general type of crime (violent crime vs. property crime). To ensure privacy and confidentiality the NIFM images were coded and entered the research project without any record of the agency, case number, suspects, known individuals, or examiners.

NIFMs were screened for minimum qualifications, and normalized (with respect to the NVID decision) using a re-assessment by a highly qualified, certified latent fingerprint examiner (PW). This resulted in the removal of additional fingermarks that were judged to be potentially identifiable. This step was not included as a means of judging or verifying a “correct” determination of NVID, but to normalize the data set using one expert’s determination, thereby reducing variability due to differences in the criteria applied.

II. B. 2. Measurements of Associative Value

II. B. 2. a. Description of Method to Measure Associative Value

The AFIS-score method used for this study was based on the initial work of Egli [25] with an extension in the form of a distortion model based on Bookstein.[26] It has been further adapted to allow the computation using auto-encoded minutiae and without the need for a reference print. The approach includes the auto-encoding of minutiae and assigns an expected score-based likelihood ratio (ESLR) based on modeling within-variability and between-variability of AFIS scores. This method is used as a means to screen for fingermarks of potential value for identification and is also available for use on-line through PiAnoS (Picture Annotation System).[27] It is further described below.

The latest ELFT-EFS test conducted by NIST [28,29] has shown that auto-encoding of marks using the MorphoBis AFIS system is on par with the manual encoding carried out by fingerprint experts, insofar as it affects the AFIS system performance. (This does not mean that the encoder does an equivalent job; rather, the job that it does results in a comparable effect.) There is indeed a complementarity between auto-encoding and manual encoding, but our objective was to automatize the process as much as possible.

A MorphoBis AFIS system, acquired in 2015, was used on this project. This system is equipped with an encoder in version 11 and matcher in version 10. The system has shown excellent performance in the latest ELFT-EFS test by NIST[28,29] and the Sagem/Morpho matcher is one that considers only minutiae in the matching process. Minutiae meeting Quality Level 11 (a quality metric associated with auto-encoded minutiae) were extracted from the NIFMs and used for ESLR computation. The AFIS system includes a background database of 963,710 fingerprints, stripped from any personal information. These fingerprints are from retired records, purged over 20 years ago by the Swiss Federal Police following an upgrade of their AFIS system. These records have been made available to the University of Lausanne (UNIL) for research purposes only and, according to data protection regulations, cannot be distributed or shared outside UNIL.[25]

Within-variability AFIS scores represent the population of AFIS scores that would result for prints that are actually from the same source. The within-variability was obtained using the scores from the comparison between a set of "pseudolatents" (generated from the NIFM) and the NIFM itself. Pseudolatents are generated using a population of thin-plate spline (TPS) distortion functions. TPS functions, based on the work of Bookstein,[26] define a unique function that maps two sets of paired points on two images. These can be used to distort any set of points from a reference image according to the TPS function. TPS has been already applied to the matching of fingerprint images.[5,30-35]

The TPS distortion functions were computed from a set of 751 cases used as the validation set for [5]. Each case has a crime scene fingermark (latent print) and a set of paired minutiae to a reference finger impression. Each case gives one TPS function that in itself reflects a potential distortion a mark may be subject to. The 751 distortion functions represent the range of distortions each mark can be subject to. For each of the NIFMs in this work, a population of 751 distorted pseudolatents was generated, representing a reasonable range of the expected distortions regularly seen in casework. The TPS method to describe within-item variability follows the approach in [5]. Here the within-source variability distribution is obtained by fitting a log-normal distribution (as in [25]) to the scores obtained from the comparison between the pseudolatents (generated from the NIFM) and the NIFM itself.

Between-variability AFIS scores represent the population of AFIS scores that results for prints that are not from the same source. Between-variability was obtained using the scores from the comparisons between the NIFM and the background database of 963,710 fingerprints, representing a set of unrelated reference prints. For a given NIFM, the between-variability distribution of scores was fitted with a Log-Normal distribution and used as the probability density function.[25]

For a given NIFM, the expected score-based likelihood ratio (ELSR) is obtained by computing the ratio at a given point that we name the "evidence score" of the probability densities of the within-variability and between-variability of AFIS scores. The evidence score used to compute the ESLR is not the score obtained from the comparison of the NIFM and itself, but is taken at the point of maximum density of the within-source variability. The "evidence score" then represents the most likely score that would be obtained should a corresponding print be available for comparison purposes.

The process was calibrated as described by Haraksim et al.[20] using a logistic regression method developed by Ramos-Castro et al.[37,38] as applied to the 258 cases from the standard NIST SD27 database.[39]

II. B. 2. b. Initiation, Testing and Evaluation of Measurement Methods

Methodology. Measurement methods were defined and evaluated using a ground truth data set of 889 latent impressions paired to reference prints from their actual source finger. Paired (corresponding) minutiae were manually annotated. From each ground truth pair a sub sample between 3 and 12 minutiae was randomly selected. Minutiae were iteratively selected from a focal point (e.g., the core) and cropped accordingly. The number of cases for each minutiae count are shown in Table 1.

Table 1. Number of Ground Truth Data Set Cases by Number of Minutiae

Minutiae	Number of cases
3-4	98
5	100
6	102
7	97
8	98
9	95
10	102
11	98
12	99
Total	**889**

Auto-encoding of minutiae was performed using a SAGEM-Morpho Light-Out system in version 10. Quality maps for latent prints were obtained using the Universal Latent Workstation (ULW v6.4.1 with LQMetrics). The AFIS used to compute the similarity scores is a Morpho DMA equipped with a matcher in version 9.

The score based likelihood ratios (SLR) were calculated following the generic model proposed by Egli,[25] enhanced by a distortion model (developed and applied in this program by Marco De Donno). The calculation for a particular mark and reference is based on modeling the within-variability and the between-variability of AFIS scores. The between-variability is obtained using the scores from the comparison between the mark and a background database composed of 963,710 fingerprints. The scores are then fitted with a Log-Normal distribution and used as the probability density function. The within-variability is obtained using the scores from the comparison of pseudo-marks generated from the reference print based on a Thin Plate Spline (TPS) distortion model as defined by Bookstein.[26] The scores are then fitted with a Weibull distribution and used as a probability density function.

For determination of expected weight of evidence (applied directly to latent prints, as opposed to latent prints matched to reference prints), the reference print is replaced with the mark itself. Within-variability is taken as the mode (maximum probability density) of the within source distribution. This is an approximately linear transformation of the evidence score, selected based on assumption that the minutiae configuration in the latent print is the most probable to be produced by the actual source.

Validation of Use of Latent Print SLRs to Predict Expected SLRs. SLRs obtained from the manually annotated latent prints and their corresponding ground truth prints were used as baseline (target SLRs) for method calibration. The first step was to evaluate the method of mapping the expected SLRs (ESLRs) obtained from the annotated latent prints alone to the ground truth target SLRs (TSLRs obtained from both the annotated latent prints and their ground truth reference prints). Figure 1 shows a very strong correlation between the ESLRs and the TSLRs (very close to the diagonal line (y = x)) for all numbers of minutiae. This demonstrates that the ESLR obtained from manually annotated latent prints reliably predicts the TSLR.

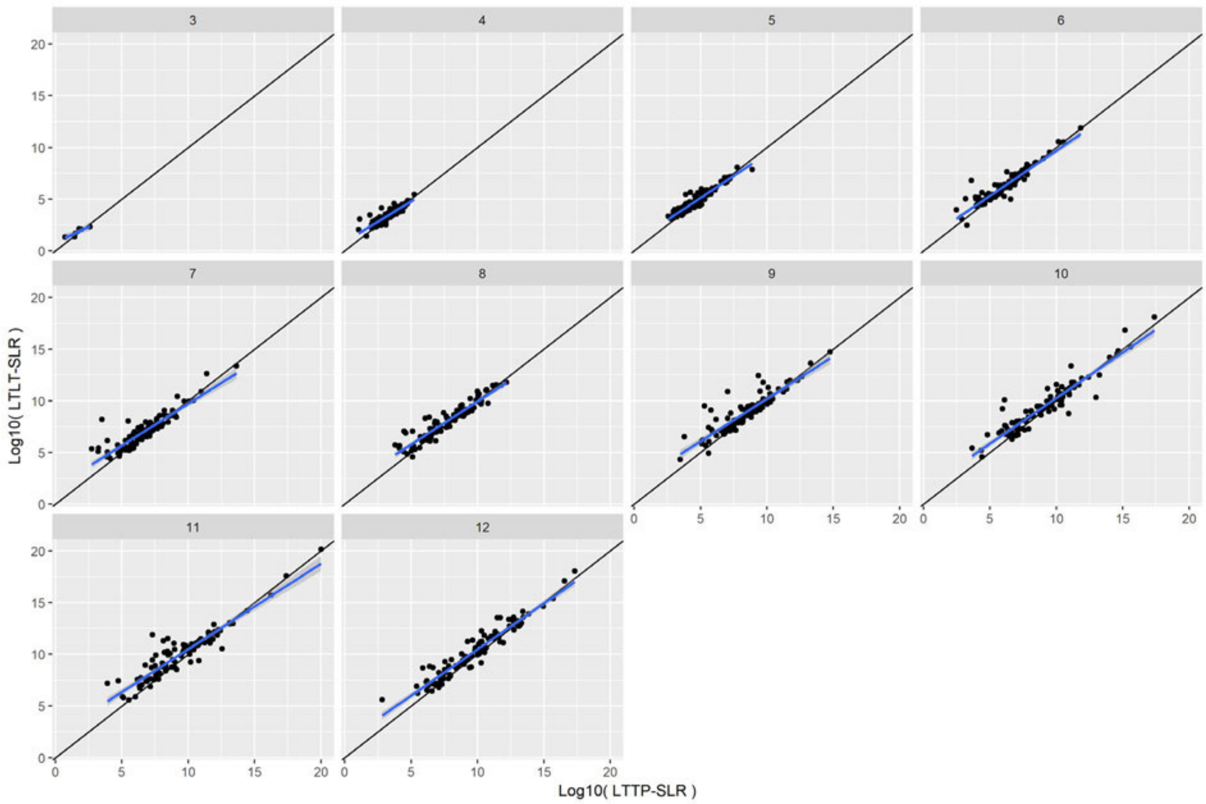


Figure 1. Vertical axis: Log_{10}(LTLT-SLR) = Expected ESLR. Horizontal axis: Log_{10}(LTTP-SLR) = Target TSLR. All 889 cases as a function of the number of minutiae annotated on the mark.

Effect of Auto-Encoding of All Minutiae in the Image. It was found that when the numbers of auto-encoded minutiae are close to the manually-encoded minutiae (+/- 1), there remains a strong correlation between the ESLR and the TSLR. However, a greater difference was frequently observed between the manual and auto encoding, as shown in Figure 2. These variations can be substantial and are due to various image factors such as background interference or even the presence of rulers in the image. There are 24 outliers (2.7%) with much greater numbers of minutiae (represented by dots above the whisker plots). Greater numbers of auto-encoded minutiae resulted in positive deviations from correlation and lower numbers of auto-encoded minutiae resulted in negative deviations. Figure 3 shows the overall effect. The individual charts have a given difference in the numbers of auto-encoded and manually-encoded minutiae. Strong correlation remains for the chart with a difference of zero. Small deviations are seen for +/- 1, and there is a regular increasing deviation as the difference in the number of minutiae increases. Individual charts show the effect of the difference of minutiae counts between the auto-encoded and manually-encoded minutiae. For example, at the upper left corner the chart labeled "-8" shows data where the auto-encoder detected 8 fewer minutiae than were manually annotated.

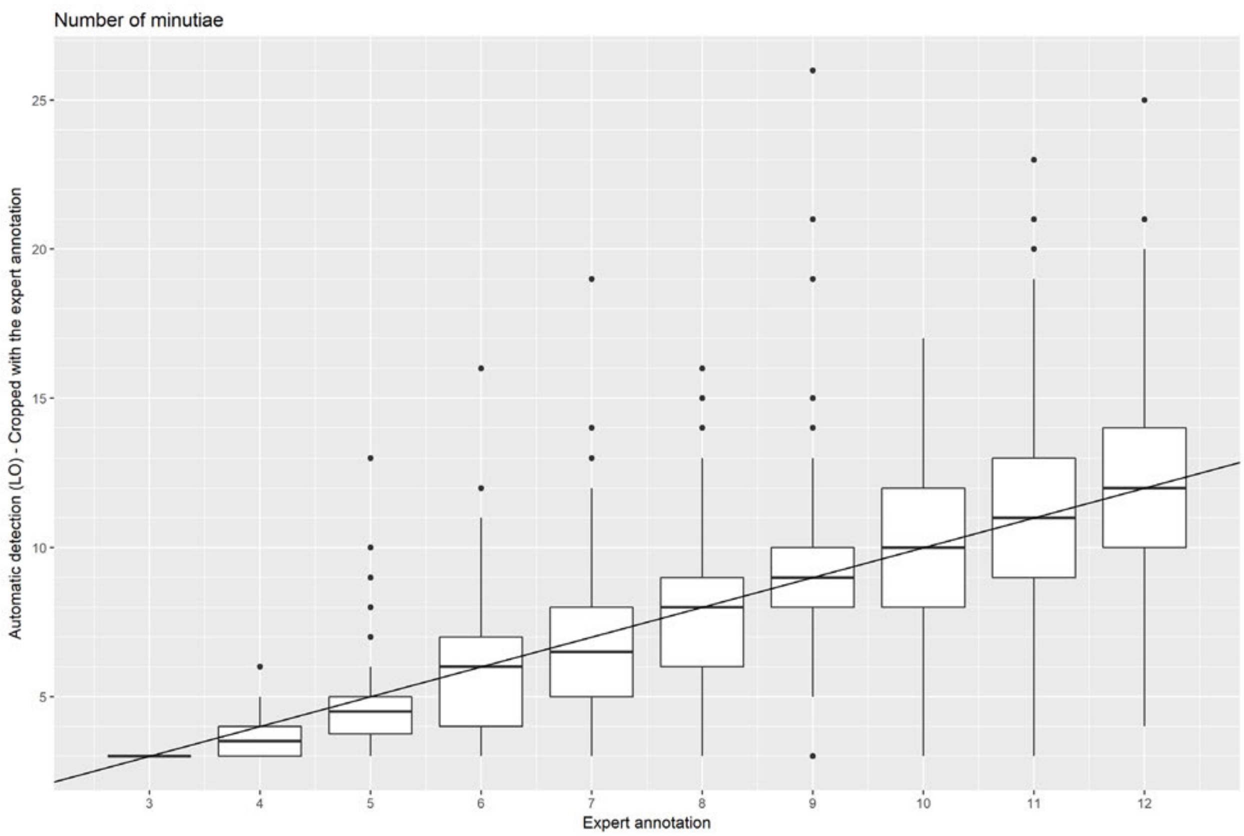


Figure 2. Number of minutiae annotated by skilled examiners (x-axis) versus auto-encoded minutiae (y-axis).

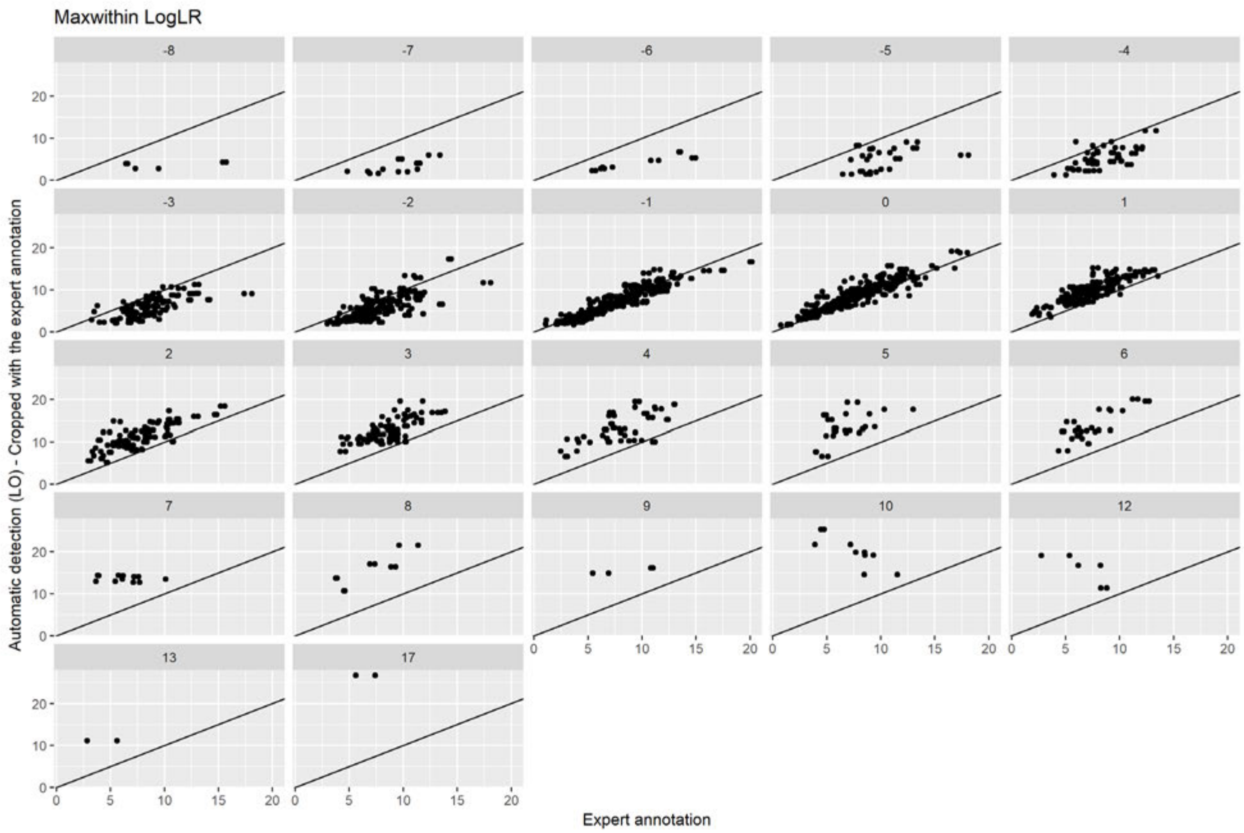


Figure 3. Vertical axis: Log_{10}(LTLT-SLR) = Expected ESLR. Horizontal axis: Log_{10}(LTTP-SLR) = Target TSLR.

Conversely, at the lower left the "13" means that the auto-encoder detected 13 more minutiae than were manually encoded. The correlation remains strong for the charts to the right of the second row where the numbers of manually annotated and automatically encoded are close.

With an unknown mark that has not been annotated by an expert (corresponding to how the system was used in this project), this difference in number of minutiae between the expert's annotations and the auto-encoding is unknown. Therefore we cannot simply apply auto-encoding.

Use of an Automated Quality Map to Select Latent High Quality Latent Print Minutiae. We used the automated Quality Map in the ULW to select those auto-encoded minutiae that were present in higher quality areas (Quality 2 and above). This allows removal of auto-encoded minutiae appearing in unreliable zones. Figure 4 shows an example. The full set of auto-encoded minutiae is shown on the left image, whereas a more restricted set comprising those in high quality areas, is shown to the right. This result is a number of minutiae that is closer to, and often lower than the annotated minutiae (Figure 5). The percentage of outliers (with a high excess of auto-encoded minutiae) has been reduced to 1.5%. With this minutiae selection procedure, the expected ESLR are closer to the target TSLR.

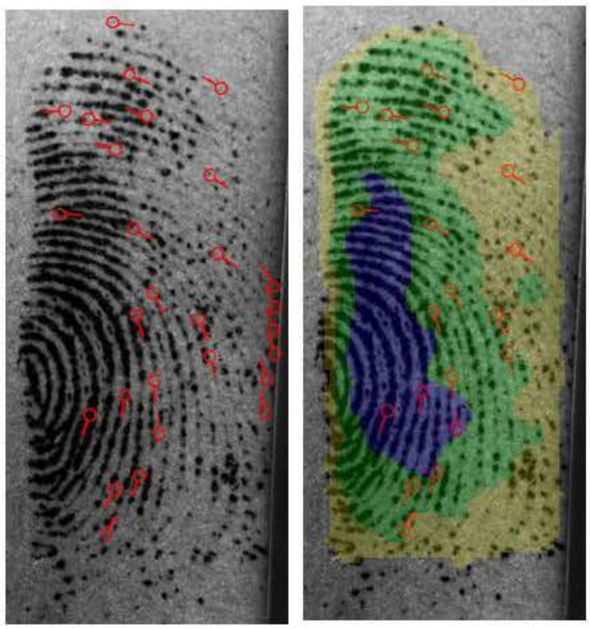


Figure 4. Left: All minutiae obtained used the auto-encoder of the AFIS system. Right: Minutiae retained in good quality areas (blue, green and yellow = Quality 2 and above using the LQMetric).

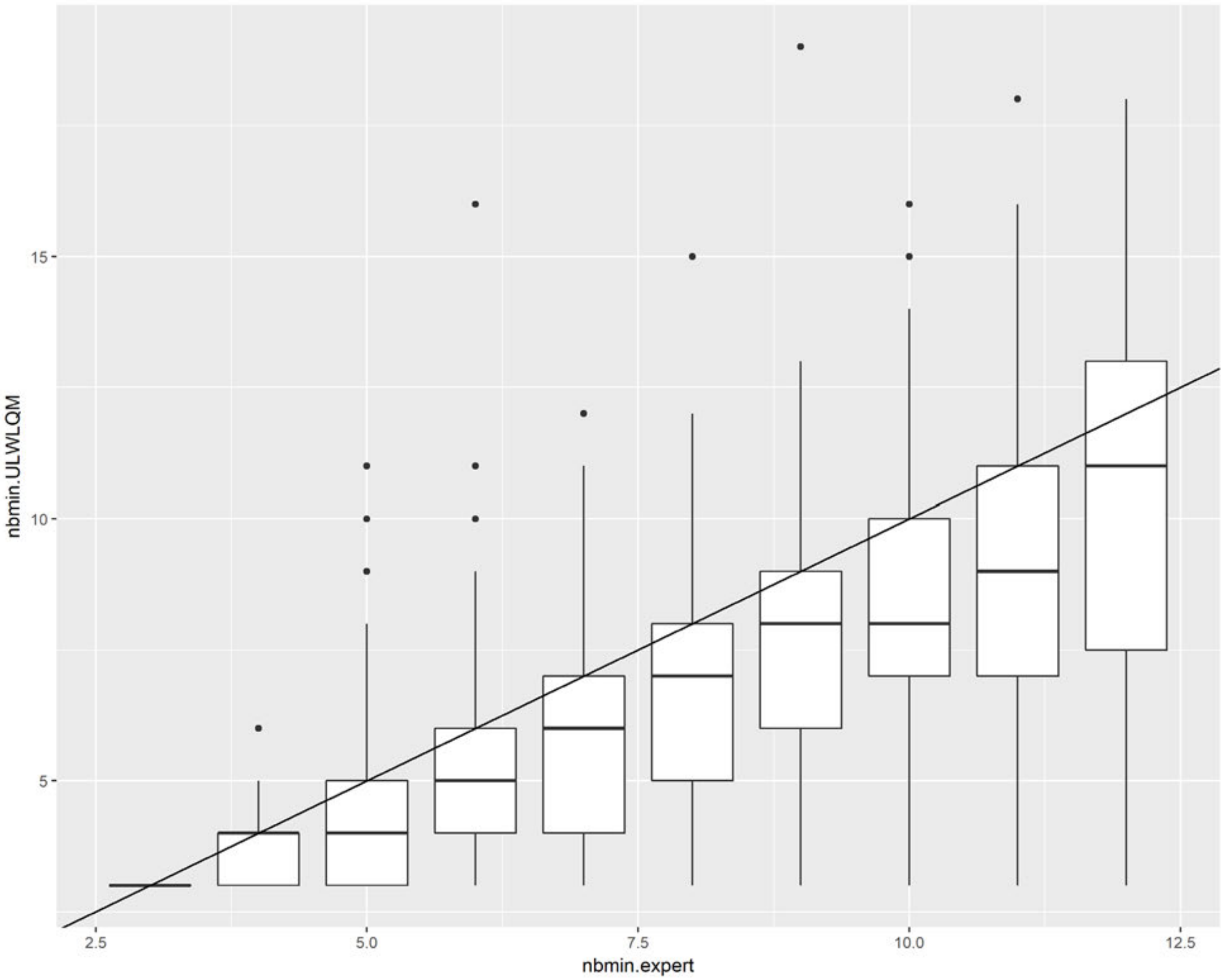


Figure 5: Number of minutiae annotated by skilled examiners (x-axis) versus auto-encoded minutiae but restricted by the quality values obtained from ULW LQmetric (y-axis).

Calibration to Obtain an Appropriate ESLR Based on Auto-Encoded Minutiae. A linear model was developed to predict the TSLR based on the ESLR obtained from high quality minutiae. These are a subset of the minutiae given by the AFIS auto-encoder: those occurring in areas where the LQMetric is Level 2 and above. If both the numbers of expert and the auto-encoded minutiae are the same, then the model gives an R^2 of 0.8537. The correlation is very strong as shown in Figure 6. Some of the spread around the diagonal line is due to potential minutiae used by the auto-encoder that may differ from the manually encoded ones.

Use of Individual Minutiae Quality Values to Select High Quality Latent Print Minutiae. The use of automated quality maps to select high quality minutiae on an initial set of 473 NVID latents resulted in 353 successful ESLR measurements (74.6%). Procedures were revised to select minutiae based on their internal quality value given by the AFIS auto-encoder (Morpho lights-out version 11). This procedure (described below) increased the yield of ESLR measurements to 433 of 473 (91.5%).

The auto-encoder output includes a quality value between 0 and 14, representing the quality for a particular minutiae (14 representing the highest quality and 0 the lowest). A threshold value of 11 was set for retention of minutiae meeting the program criteria of “clear Level 2 ridge detail.” This selection was based on a sampling of 7,761 minutiae, examined by an experienced AFIS operator, making judgements for inclusion or exclusion as an annotated minutia feature for AFIS entry. Most minutiae of quality 11 and above were clearly defined, meeting a threshold for coding by an experienced operator, whereas most minutiae quality 10 and below were not. Illustrations of minutiae of quality levels 14 and 11 are given in Figure 7.

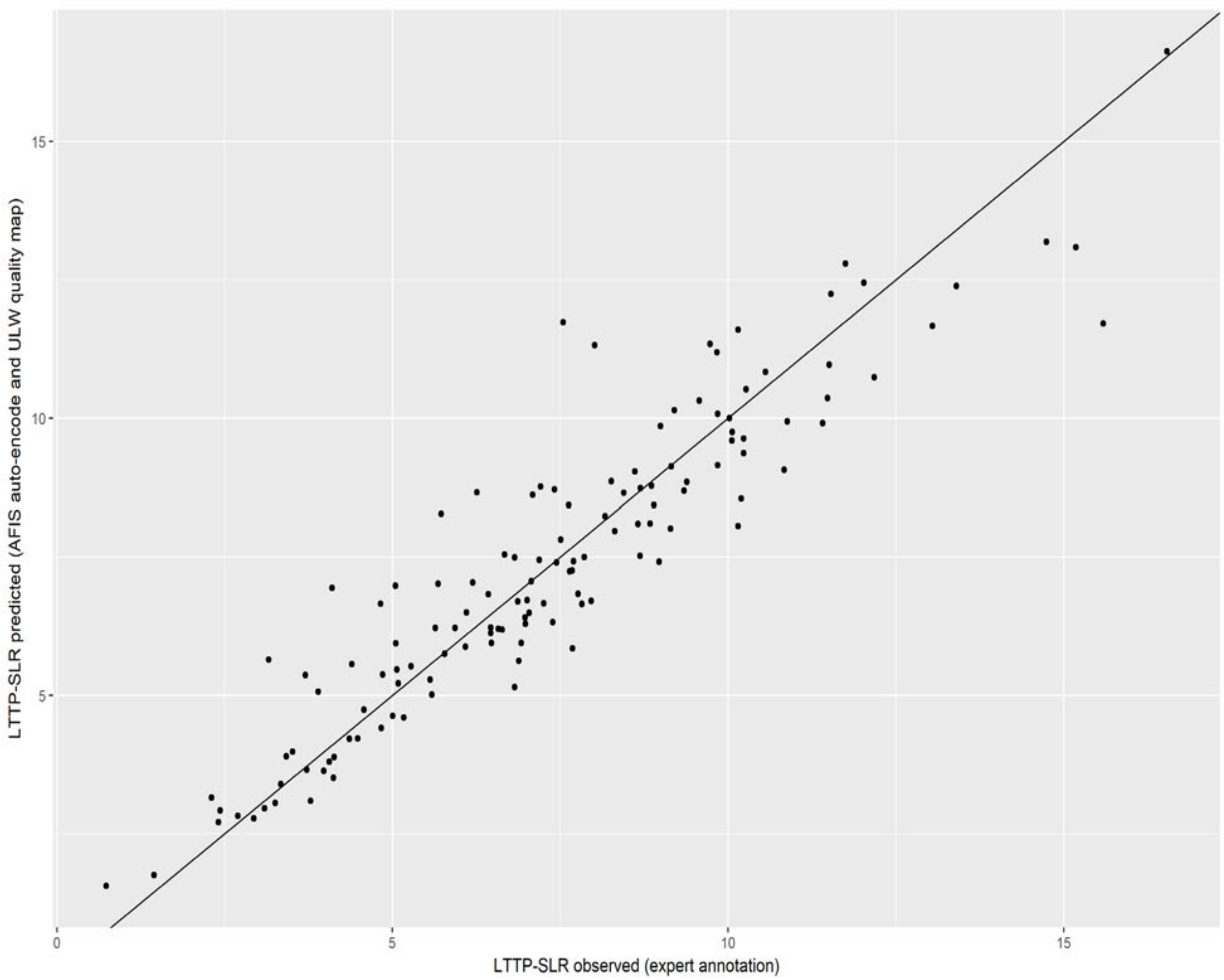


Figure 6: LTTP-SLR predicted (AFIS auto-encoder and ULW quality map) vs. LTTP-SLR (based on expert annotation).

Figure 7. Left two images: Illustration of two minutiae of quality 14 (highest). Right two images: Illustration of two minutiae of quality 11 (threshold).

Sensitivity Analysis of the ESLR Measurement. Image processing parameters were simulated jointly, exploring the ranges of ESLRs when applying a set of reasonable random variations to the following variables: contrast, luminosity, exposition, size and rotation.

For a given NVID latent print image, ESLRs were computed on 100 simulations, each instance representing a given state of the variables of interest. The variations were obtained by a set of 100 vectors of 5 values (one for each variable) obtained from the random sampling from five truncated normal distributions. The truncated-normal distributions are defined by the parameters given in Table 2. The seed is the value passed to the Python Numerical Library to generate repeatable truncated-normal samples. These random seeds are important to ensure the repeatability of the ESLRs obtained from a given input image. The lower limits, upper limits, and the standard deviations were set to represent reasonable variations in photographic conditions. The mean is set to the “original” value for the particular parameter (i.e. no modification is applied to the image).

Table 2. Parameters used for Sensitivity Analysis

Variable	Seed	Mean	SD	Lower limit	Upper limit
Contrast	1	1	0.25	0.75	1.25
Luminosity	2	1	0.25	0.75	1.25
Exposition	3	0	0.25	-0.50	0.50
Size	4	100%	10%	90%	110%
Rotation	5	0°	45°	-90°	90°

An example of all of the 100 simulated images obtained for a given NVID latent image is shown in Figure 8. Separate ESLRs are then computed for each image. The results for 100 ESLRs for 473 NVID latent print images are shown in Figure 9. The range of ESLR values, represented by box plots, are centered about the median value for each NVID latent print. The deviation from the median is expressed in $\log_{10}$.

The spread around the median is relatively small for the majority of the cases, but can be large in some cases. Overall, when we look at the 50% of the most centered points (the values between percentiles 25% and 75%), the distribution of ESLRs around the median is shown in Figure 10. The spread is about of one order of magnitude of the ESLR.

Figure 11 shows the distribution of the 25% to 75% ranges of the ESLRs plotted against the median of the ESLRs itself (expressed in $\log_{10}$). The range between the 25th and 75th percentile is seen to increase as the median ESLR increases. Overall, the sensitivity is approximately ± 1 order of magnitude for ESLR below 5, ± 1.5 between 5 and 10 and ± 2 for ESLR above 10.

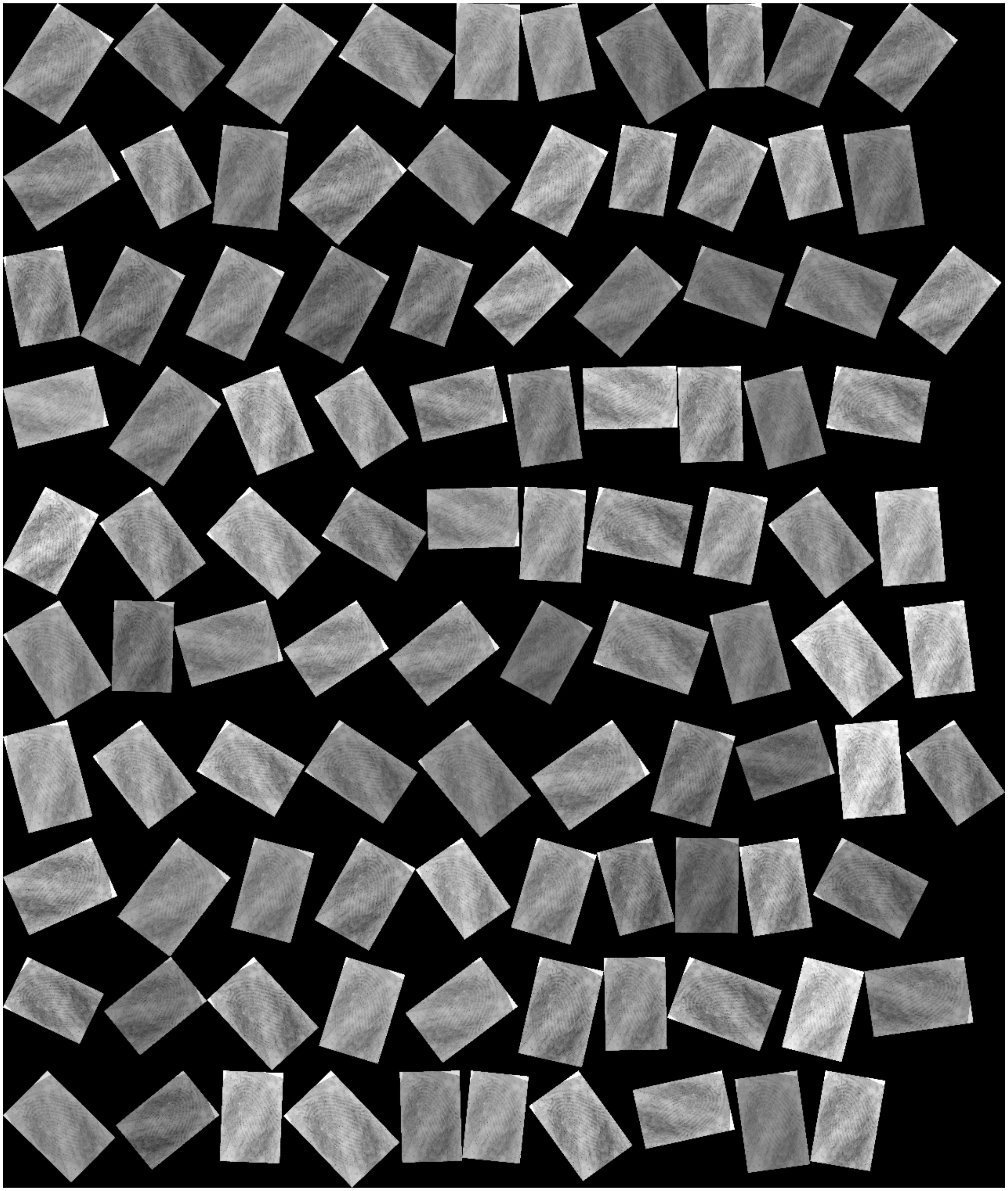


Figure 8. The set of 100 images resulting from a single NVID latent print. The images are generated by image processing according to the set of resampled values from the truncated-normal distributions for the attributes contrast, luminosity, exposition, size and rotation.

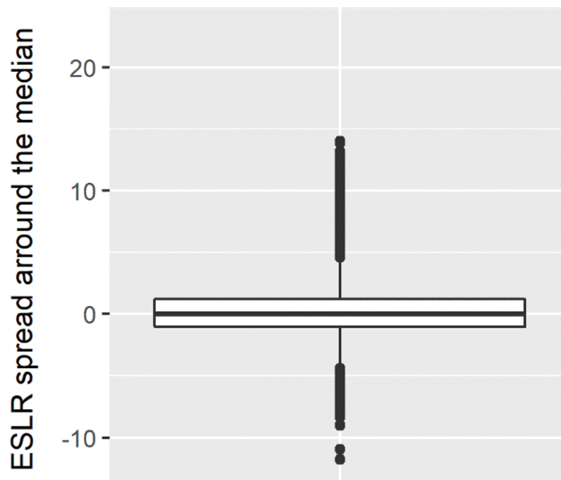


Figure 9. Distribution of the deviation of the ESLRs relative to their median, obtained following 100 simulations of the variables (contrast, luminosity, exposition, scaling and rotation). For each case (leading to different median ESLRs), the median is shifted to 0 and the deviation from the median is recorded in $\log_{10}$.

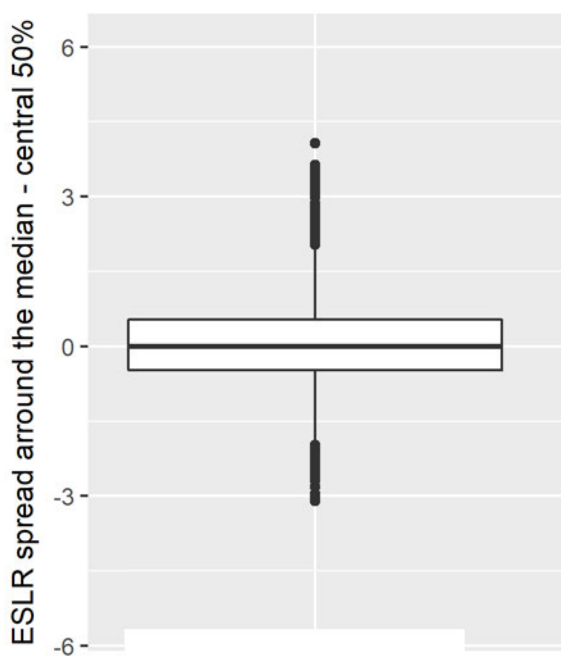


Figure 10. Replotting of Figure 9 restricting to data within the 25 and 75 percentiles.

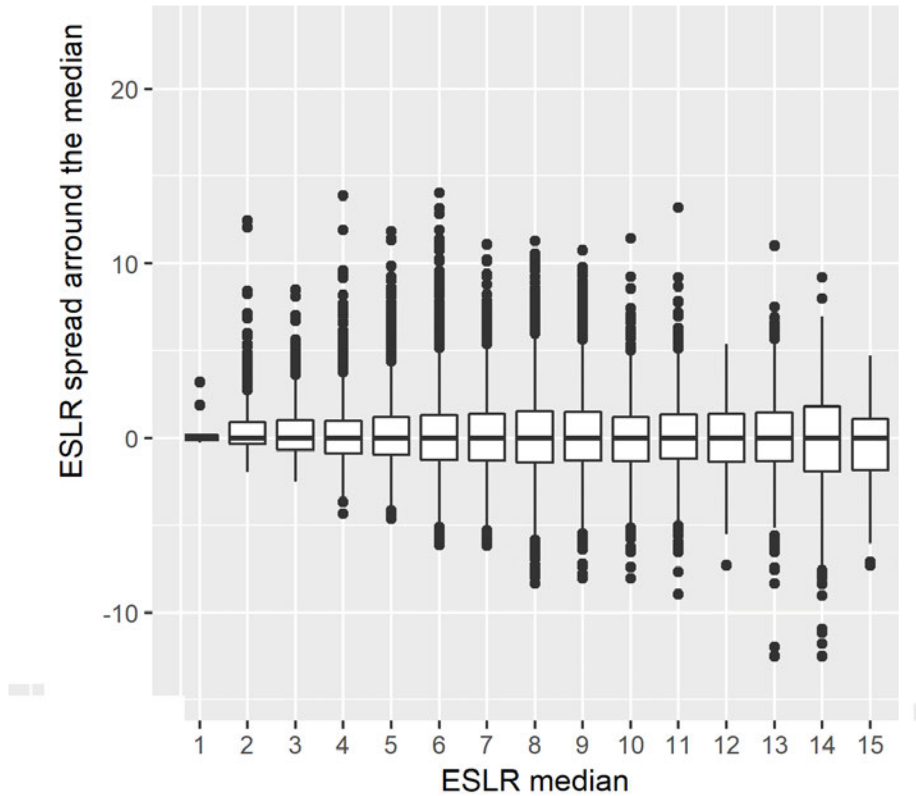


Figure 11. Distribution of the ranges in $\log_{10}$ ESLR about the median (expressed at the spread between 25% and 75% percentiles) as a function of the median of the ESLR.

Effect of Expert Encoding of Minutiae vs Automated Extraction. The ESLR methods were specifically designed to employ automated feature extraction to avoid (for purposes of this research) introduction of variation attributable to individual expert judgements. Applications of ESLR measurements to casework will likely involve expert coding of minutiae. To provide a measure of the effect of this difference, a randomly selected 10% of the 750 NVID latents were manually encoded using the PiAnoS interface by Pat Wertheim (the same expert used for the normalization of the NVID latents in this research). Of the 75 expert-encoded NVID latents, 64 were suitable for ESLR measurements (the other 11 showing configurations that were not searchable by the AFIS).

Table 3 shows descriptive statistics contrasting the Log_{10} ESLRs and minutia numbers. Mean Log_{10} ESLRs differ by an order of magnitude, with expert encoding showing a value of 4.37 (one in 23,000) and auto-encoding showing 5.36 (one in 230,000). The mean minutia numbers show 0.88 more minutiae resulting from auto-encoding.

Auto-encoding shows a much wider range of minutia numbers (15 vs 5). Histograms for the Log_{10} ESLR are shown in Figure 12 and those for minutia numbers are shown in Figure 13. The auto-encoding results show greater numbers of latents with high Log_{10} ESLRs, as well as greater numbers of latents with higher numbers of minutiae. However, these trends are an

Table 3. Descriptive Statistics Contrasting Log_{10} ESLR and Number of Minutiae for Auto- and Expert-Encoded Minutiae

Log_{10} ESLR		
	Auto	Expert
Mean	5.36	4.37
S.D.	2.44	1.69
Range	9.71	7.02
Min	1.06	1.80
Max	10.77	8.82

Number of Minutiae		
	Auto	Expert
Mean	6.44	5.56
S.D.	2.48	1.39
Range	15	5
Min	3	4
Max	18	9

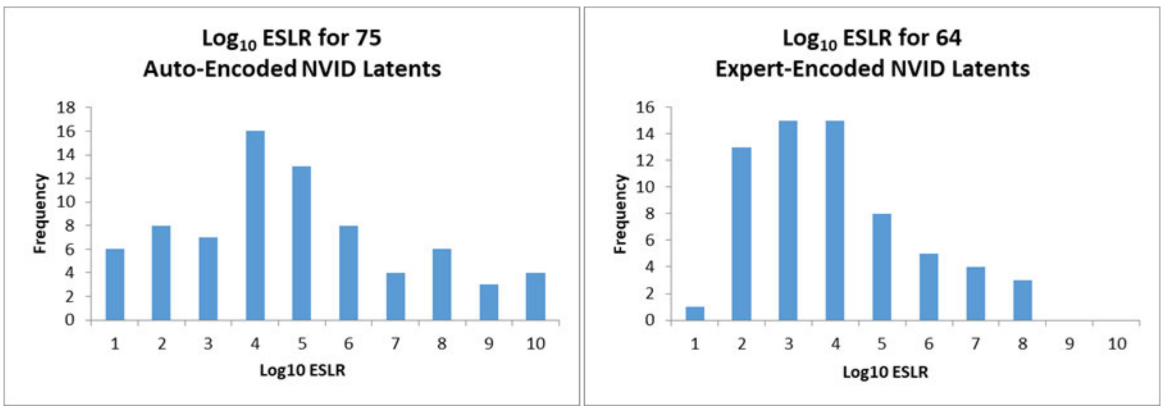


Figure 12. Histograms for the Log_{10} ESLR for auto-encoded minutiae (left) and expert-encoded minutiae (right).

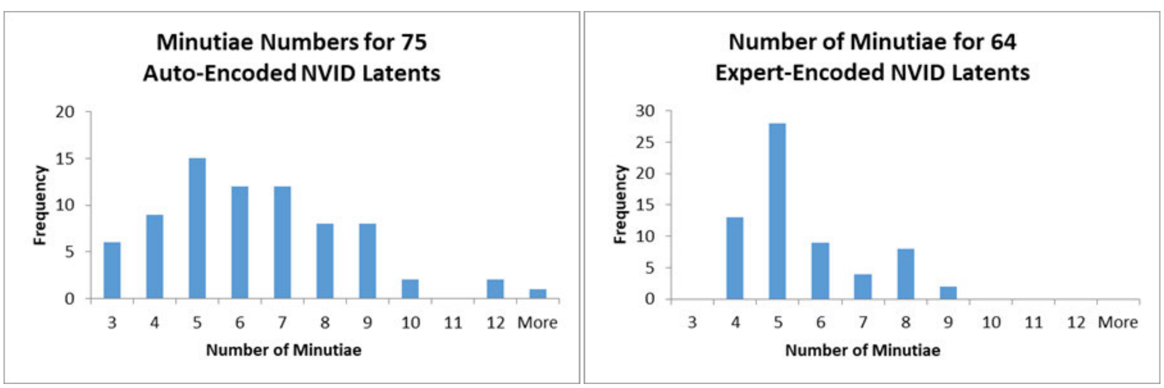


Figure 13. Histograms for the number of minutiae from auto-encoding (left) and expert-encoding (right).

oversimplification of the data. Figure 14 shows a scatterplot of the differences between the Log_{10} ESLRs and numbers of minutiae (subtracting expert-encoded values from auto-encoded values).For minutia numbers (horizontal axis), there are nine auto-encoded latents that show an excess of 4 or more auto-encoded minutiae. One of these shows an excess of 7 and another shows an excess of 14. For a comprehensive study of the methodology, the causes of these exceptional cases is worthy of study. Setting these 9 aside, the remaining data show minutia numbers differing by three or less. For these 55 latents, 12 show equal numbers of minutiae, 25 show more minutiae by auto-encoding, and the remaining 18 show more minutiae by expert-encoding.

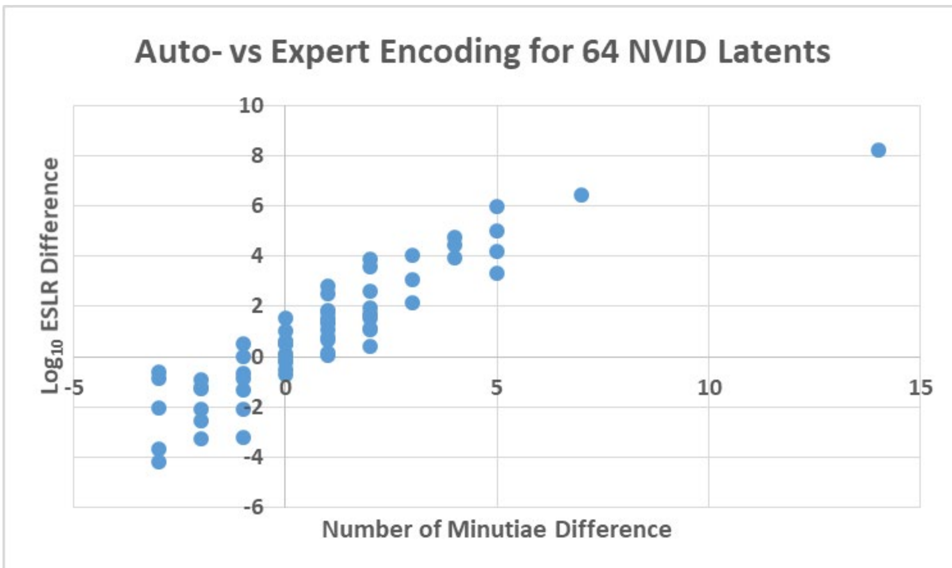


Figure 14. Scatterplot of differences in Log_{10} ESLR values and numbers of minutiae between auto- and expert-encoded latent prints.

II. C. Results: Occurrence and Associative Value

A total of 1668 fingermark images, representing 890 cases, were collected from 9 jurisdictions within the USA. Expert review resulted in removal of 32.4% of the marks on the basis that they were potentially identifiable and removal of another 4.8% of the marks on the basis that they did not meet the minimum requirement of 3 clear and reliable minutiae with clear relationship to each other within the ridge structure. The remaining 1048 NIFMs were auto-encoded and an additional 21.0% were removed as they failed to show the minimum of 3 auto-encoded minutiae above Quality Level 11. ELSRs were measured for the remaining 828 NIFMs.

Figure 15 shows values of Log_{10} ESLR for the 828 NIFM meeting program requirements. Seventy eight of the ESLR values exceed a world population estimate of 77 billion fingers ($Log_{10} > 10.88$). Figure 16 shows the values for the remaining 750 NIFMs. There is a mean value of Log_{10} ESLR of 5.56 (s.d. 2.29), corresponding to an ESLR of approximately 380,000.

Of the 750 NIFMs, 540 were from property crimes (largely burglaries and thefts), whereas 210 were from violent crimes (largely homicides, robberies and assaults, but including 33 from drug and firearm related crimes). The breakdown in case types and latent prints by laboratory is given in Table 4. Figures 17 and 18 show the distribution of ESLR values for these two subsets of the NIFMs. Possible sources of differences include the extent of crime scene processing, and agency policies regarding the collection and retention of latent prints.

Table 4. Breakdown of NVID Latents by Laboratory and Violent vs. Property Crimes

	Crime Type	
Laboratory	Property	Violent
A	48	0
B	26	37
C	5	4
D	9	1
E	159	17
F	78	56
G	3	16
H	140	42
I	72	37
J	540	210

Figure 19 shows regression analyses of the associative value measurements (Log_{10} ESLR) as a function of four objective quality measurements used as part of the latent print characterization. Although the algorithms of Yoon et al.[21,22] show low positive correlations (adjusted R square values of 0.09 and 0.10, respectively), they show little predictive value. The Universal Latent Workstation (ULW) measures of overall quality and overall clarity [23] show negligible correlation. Given the basis for the calculation of the ESLR value, this is not unexpected. Once minutiae are detected and accepted as a basis for matching (based on meeting a quality threshold of 11) they are used in the computation. The overall quality and clarity of the print does not enter the calculations. With NIFMs we are operating at such a low quality overall that the algorithms tested cannot distinguish easily among these marks.

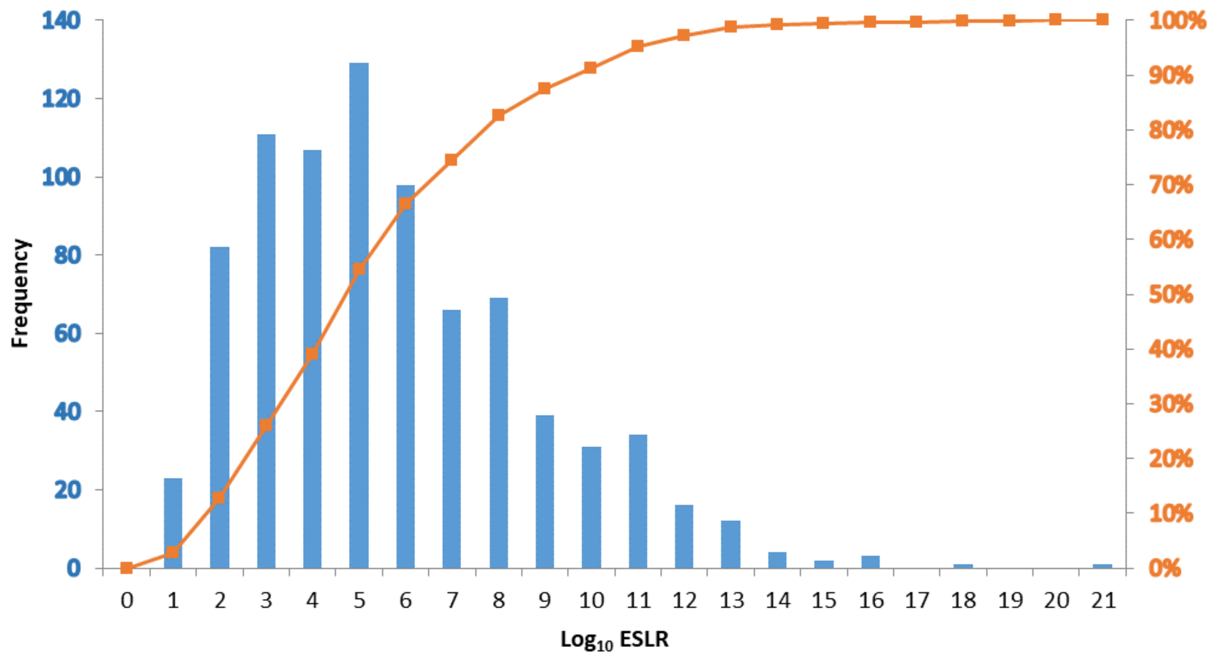


Figure 15. Log_{10} ESLR for the 828 NIFMs meeting program requirements. For example, the bar above the number "5" shows 129 NIFMs. Assuming the selection of the correct individual and a good correspondence with the NIFM print, we would expect an ESLR with a weight of evidence of 10^5 for any of these 129 NIFMs. By analogy, the weight of this evidence would be as if we found matching characteristics that would occur randomly in one in 10,000 individuals (one in 100,000 fingers).

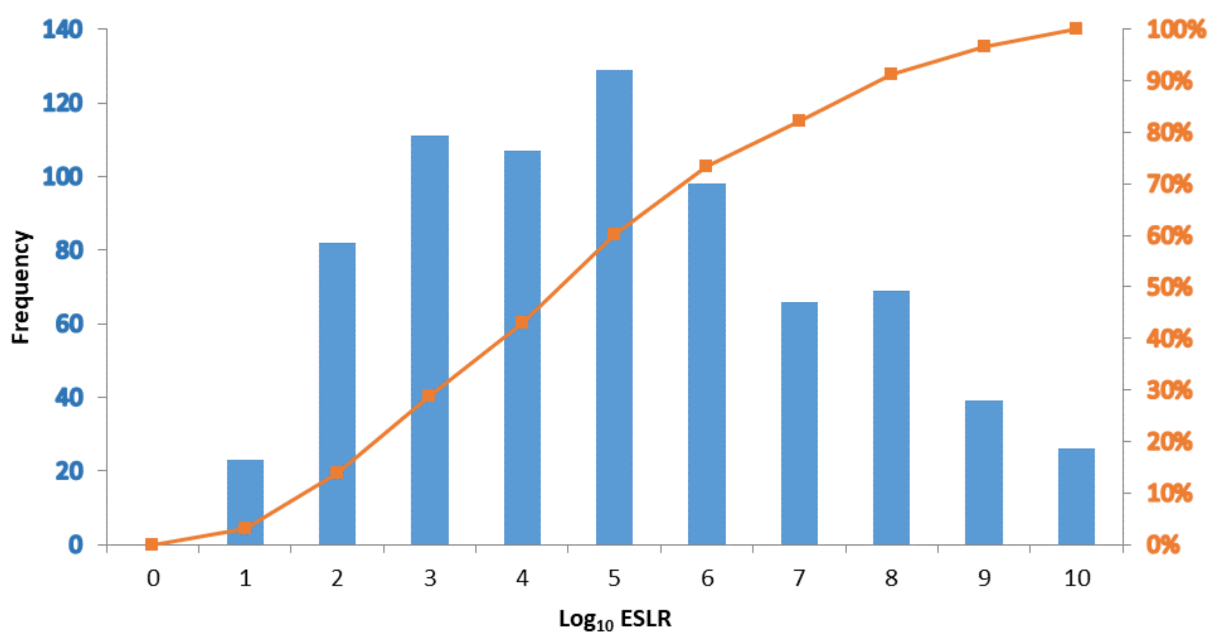


Figure 16. Log_{10} ESLR for the 750 NIFMs with values of Log_{10} ESLR below 10.88.

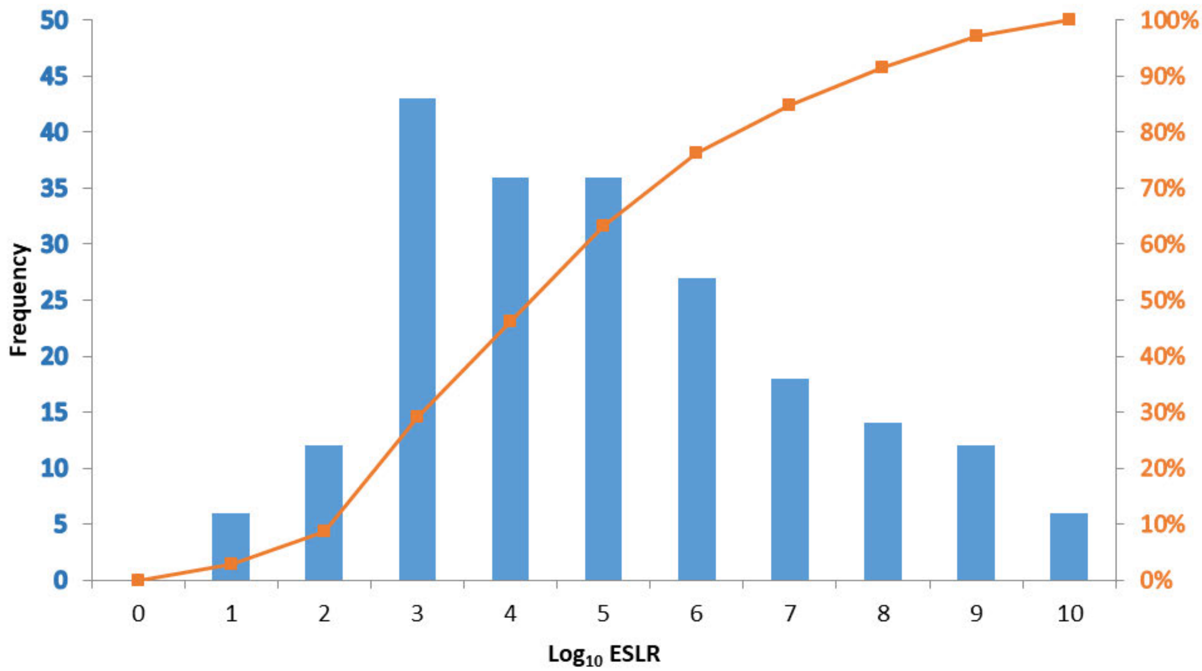


Figure 17. Associative value measurements (Log_{10} ESLR) for the 210 NIFMs from violent crimes with values below 10.88.

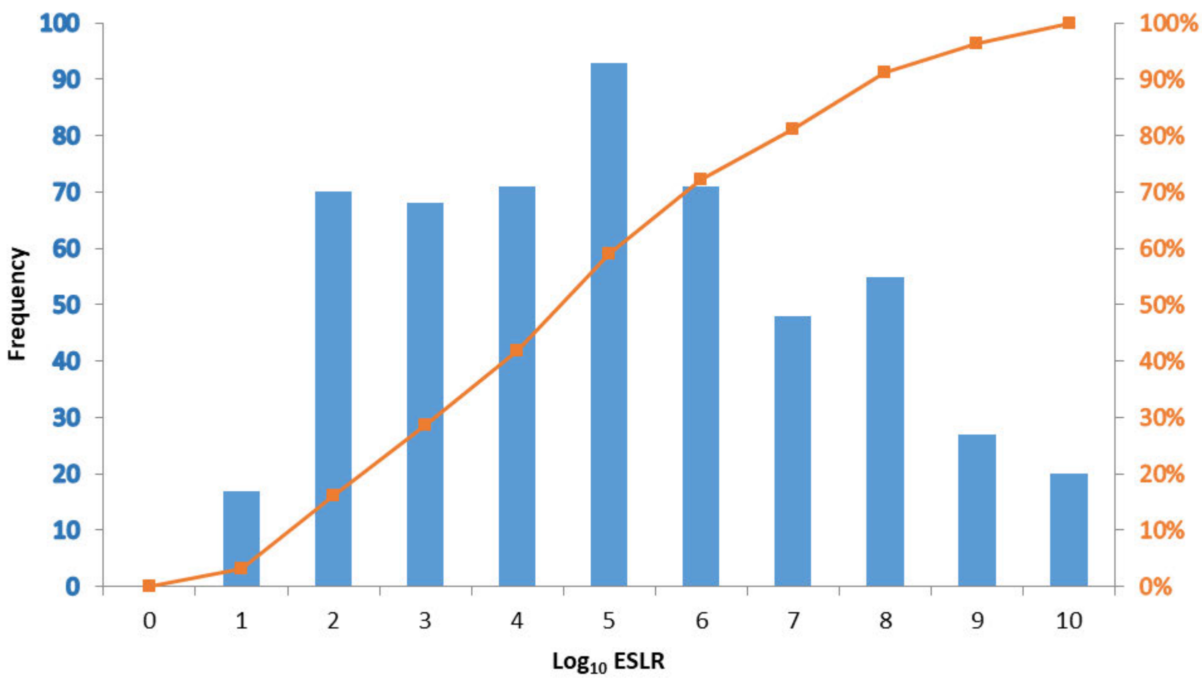


Figure 18. Associative value measurements (Log_{10} ESLR) for the 540 NIFMs from property crimes with values below 10.88.

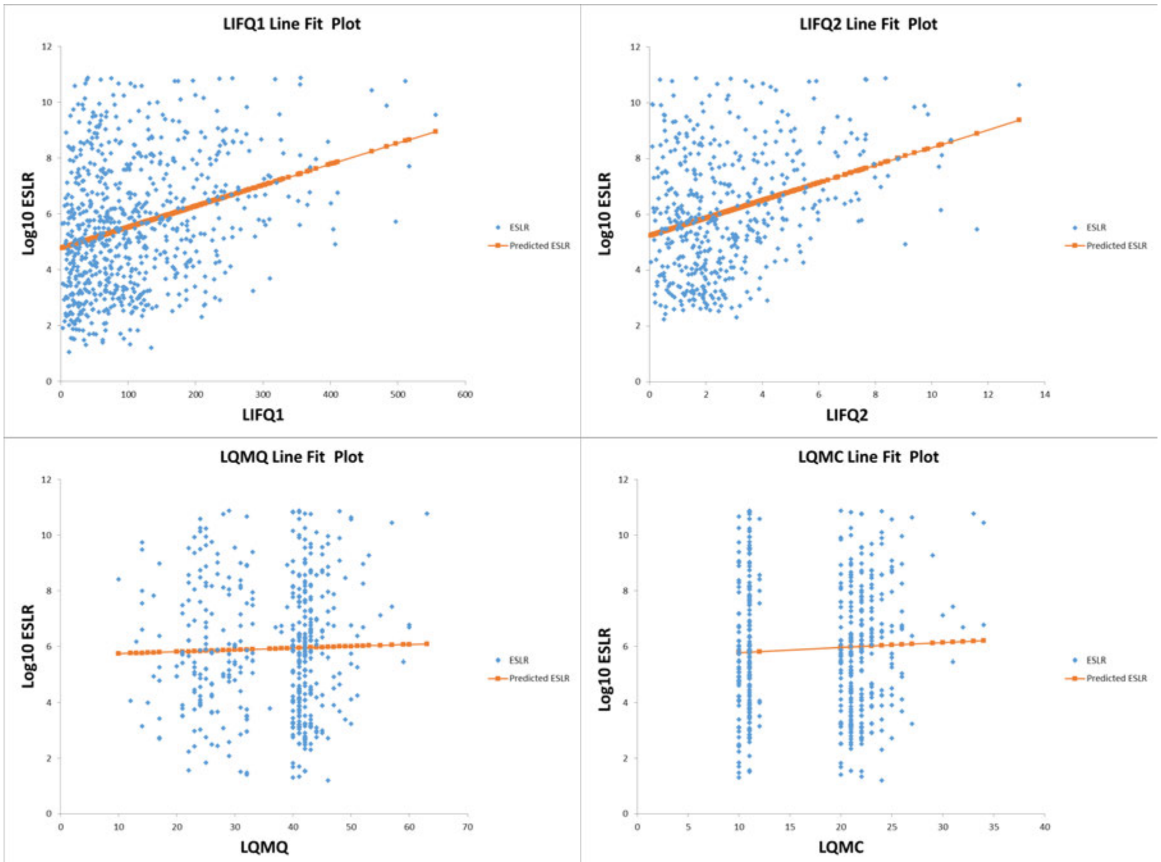


Figure 19. Regression analyses of associative value measurements (Log_{10} ESLR) as a function of four quality measurements. Upper Left: LIFQ1,[21] Upper Right: LIFQ2,[22] Lower Left: ULW measure of Overall Quality (LQMQ),[23] and Lower Right ULW measure of Overall Clarity (LQMC).[23]

Figure 20 shows regression analyses of the associative value measurements (Log_{10} ESLR) as a function of the number of the auto-encoded minutiae above quality level 11. Although there is a clear correlation (adjusted R square value of 0.75), there is a wide range in ESLR values for any given number of auto-encoded minutiae. It shows that for a given quantity of minutiae, we can expect a range of ESLR depending on the selectivity of the minutiae.

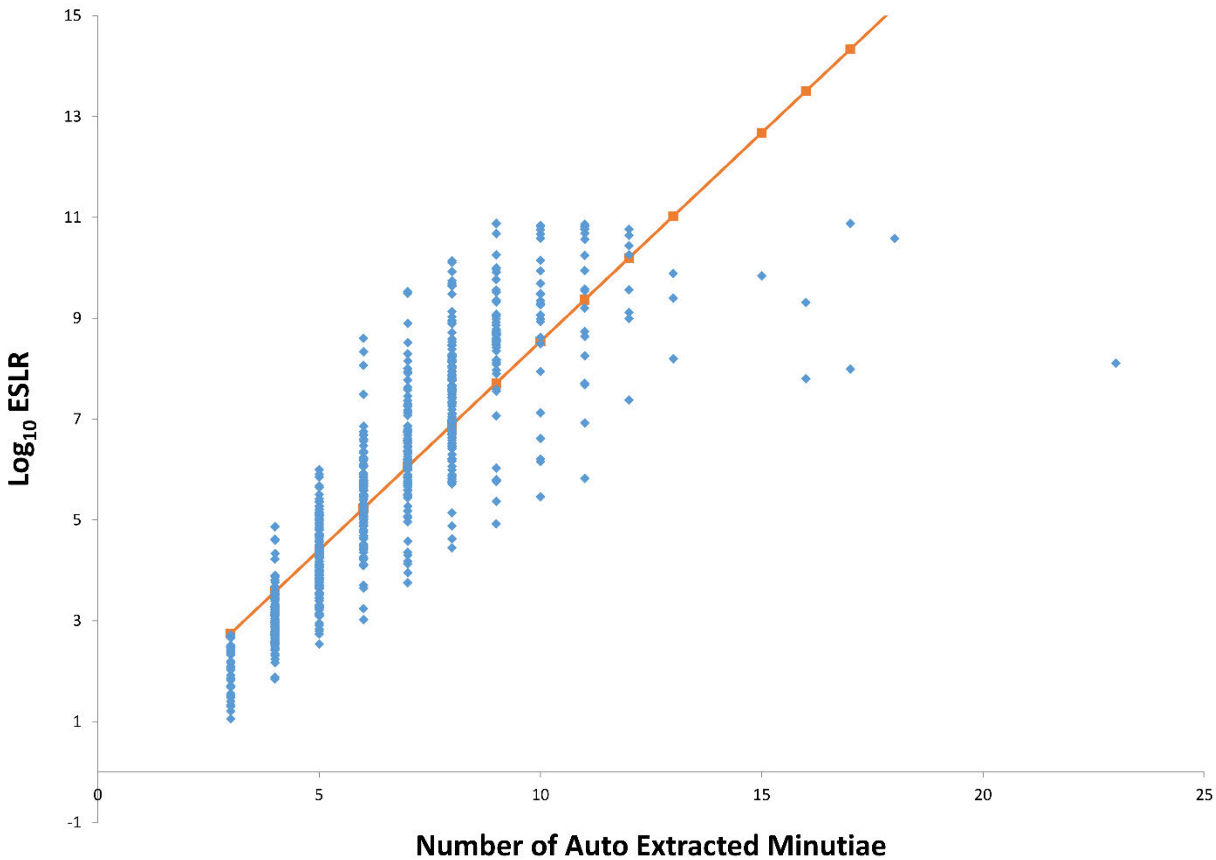


Figure 20. Regression analyses of associative value measurements (Log_{10} ESLR) as a function of the number of auto-extracted minutiae for the NIFMs.

II. D. Discussion

It is clear that NIFMs commonly occur. In cases where fingerprints of value for identification occur, there are almost always NIFMs and in greater abundance. While it was not tested, it is likely that NIFMs also occur in cases where latent fingerprints are not collected for one reason or another (for example, on unfired rounds of ammunition, where past experience indicates that identifiable fingermarks are not to be expected). It is also clear that objective, quantitative measures of associative value, such as the ESLR, can be applied to NIFMs and that there is a strong potential for a high degree of association.

This work selected and applied one method for measurement of associative value, recognizing that such methods are currently under active development,[6-14] and that they are not yet sufficiently defined and vetted for widespread use and acceptance. In particular, whether an AFIS-score based system is the best option to assign the weight to latent print evidence is currently debated.[9,17-19] That being said, we think that any model has its place as long as an empirical validation is carried with it. In this study, we have validated our method using the approach developed by Ramos and colleagues[37,38] using the NIST SD27 data set.[39] We would expect that alternative models would produce data that might vary in scale, but would lead to the same conclusions about the occurrence and associative value of NIFM evidence.

The auto-encoding of minutiae, use of an AFIS-score model and calculation of an expected likelihood ratio value without resource to a putative source, are major features of the approach used here. These were selected recognizing a research goal for an overall, examiner independent, assessment of the occurrence and value of NIFMs under existing investigative and laboratory practices. An actual evidential assessment of the associative value of a NIFM comparison would reasonably (1) rely on paired features between a fingermark and reference fingerprint, (2) incorporate expert annotation of features (rather than relying solely on auto-encoding of minutiae), and (3) involve a well-defined and vetted method for measurement of associative value. That being said, the method presented here offers a way to assess NIFMs on a systematic basis and to assign priorities and expectations. The method is fully automatic and is independent from the examiner. It can act also as an independent quality measure, part of the mark vetting process used by the laboratory or a secondary triage system.

Apart from the use of a distinctly different method for measurement of associative value, the present work could also benefit from refinements in the approach. These include studies of the variability and reproducibility of the distributions of the ESLR for this data set; variability in assessments of the ESLR for individual NIFMs introduced by aspects such as contrast, background noise, cropping, sizing and rotation; the understanding of the poor predictive value of current quality metric algorithms; and investigation as to the causes of outliers in the data set that show high numbers of auto-extracted minutiae (e.g. those with more than 14 in Figure 20).

The work could also be expanded by incorporating more jurisdictions, increasing the number of NIFMs and determining the sensitivity of the measurements to the use of alternative AFIS databases.

Comparison of auto-extraction and manual encoding of minutiae is also a reasonable line of investigation. However, this would introduce of a source of subjectivity and manual process that we specifically sought to avoid in this assessment of occurrence and associative value.

While exploration of these refinements and improvements is of value, and would improve both the accuracy of the methods and our understanding of their limitations, it would not reasonably change the fundamental conclusions of this study. The method used here is sufficiently developed to address the research questions about the occurrence and associative value of NIFMs in this project. As this model, and others, are improved, a re-analysis of the data in this study is likely to produce more accurate measures of the associative values, but is very unlikely to produce differences that would affect the answers to these questions. This research shows that there are many marks, currently declared as not sufficient for identification purposes, which offer the prospect of strong associative evidence.

III. Part 2 - Potential Contributions and Issues Affecting Utility

III. A. Overview and Objectives (Part 2)

The finding of large numbers of cases where NIFMs occur with high potential associative value leads to the follow-on questions, "How useful would NIFM evidence be in actual practice?" and, "What developments or improvements are needed to maximize this contribution?" The goal of Part 2 was to make a realistic assessment of the potential contributions of NIFMs within the criminal justice process and to identify issues affecting their utility. There were two objectives:

1. Summarize and explain the results of Part 1 to a broad audience of criminal justice participants and stakeholders, obtaining their individual reactions, including views on the potential contribution, issues that would affect this contribution, approaches to development, and areas of concern.

2. Consolidate and interpret these individual reactions into an overall assessment of NIFM evidence and an assessment of its utility in different stages of the criminal justice process.

III. B. Methodology (Part 2)

III. B. 1. Input Sources

Our objective was to capture the broadest possible range of ideas and perspectives in response to the question of the potential contribution of NIFM evidence, given the findings from Part 1. Toward this end, we presented and discussed the findings with many individuals, including police investigators, prosecutors, judges, defense attorneys, forensic scientists and members of the academic and research communities (see acknowledgements). Although some informative sessions included presentations to groups of individuals, most of the input was obtained through direct, 1-on-1 discussions. Our choice of individuals was not systematic; rather, it was weighted toward those with many years of experience, and included, where possible, professionals who had worked in multiple professional roles or positions throughout their career. The full group consisted of roughly equal numbers of police investigators, prosecutors, judges, defense attorneys, forensic scientists and academicians/researchers. Special presentations were also made to the Crime Scene Subcommittee and Friction Ridge Subcommittee of OSAC.

Our assessment is that this group is very broad and that the discussions were able to capture most ideas, perspectives, concerns and needs relating to the potential use of NIFM evidence. While our input sources are sufficient to meet the goals of this project, and we sought to avoid personal bias in the selection of this group, we did not undertake a systematic survey. It would be inappropriate to consider the views we encountered to be representative of any particular professional group. Neither can the sources be considered exhaustive: we have undoubtedly missed or overlooked some ideas.

III. B. 2. Input Method

By design, our approach evolved as the work progressed. Our initial presentations resulted in refinements addressing commonly occurring questions and incorporating the characteristics of NIFM evidence. Our later presentations incorporated crime-scene illustrations highlighting these characteristics along with possible contributions. The initial and final approaches are given later in this section, with accompanying explanatory text. (As noted, the final presentation introduces and illustrates some of the characteristics of NIFM evidence. Its review will foreshadow Section III. C., which discusses the overall character of NIFM evidence.)

For most individuals and audiences, the approach required communication of technical and scientific details in a way where the essential meaning could be clearly understood, while avoiding potential distractions and misinterpretations. This is analogous to a forensic scientist's role during testimony to the trier of fact with a balance between strictly precise scientific language and that which actually conveys the meaning to the audience. This should be borne in mind when reading the explanatory text used in the presentations. The actual communications were informal and interactive, allowing for clarifications, expanded explanations, and adaptation to backgrounds of the particular individual or audience.

Our 1-on-1 interviews and small group discussions covered a target set of topics and issues, but were open-ended, designed to elicit input on any related aspect. This was followed by prompting of responses to alternative case circumstances, investigative situations and evidential scenarios. Where time for Q&A discussion was limited (e.g. presentations to professional groups) the Q&A discussions were supplemented with written questionnaires, informal follow-on discussions, and invited correspondence. Input was invited on a wide range of topics, particularly:

(1) The assessment of potential contribution of NIFM evidence to areas such as aiding criminal investigations and investigative decisions, providing more information from available evidence, aiding prosecutorial decisions pre-trial, evidence offered at trial as part of the prosecution's case, evidence offered at trial as part of the defendant's case, use in post-conviction activities, and use in cold-case investigations.

(2) Issues (e.g. flaws, problems or limitations) that would need to be addressed to realize these potential contributions, with examples of situations where the issues would cause difficulties or concern.

(3) Suggestions on developments that would help address these issues.

III. B. 3. Initial Approach

Our initial approach, designed for presentation to a set of police investigators and prosecutors, included a six-slide PowerPoint presentation following the sequence:

1. Fingerprints as we now look at them and the research questions
2. Approach to the research questions
3. How associative value is being determined
4. Chart of Part 1 research results
5. Explanation of Part 1 research results
6. Next (current) steps

Figures 21 through 26 show these PowerPoint slides, with captions describing the main explanations and discussion points.

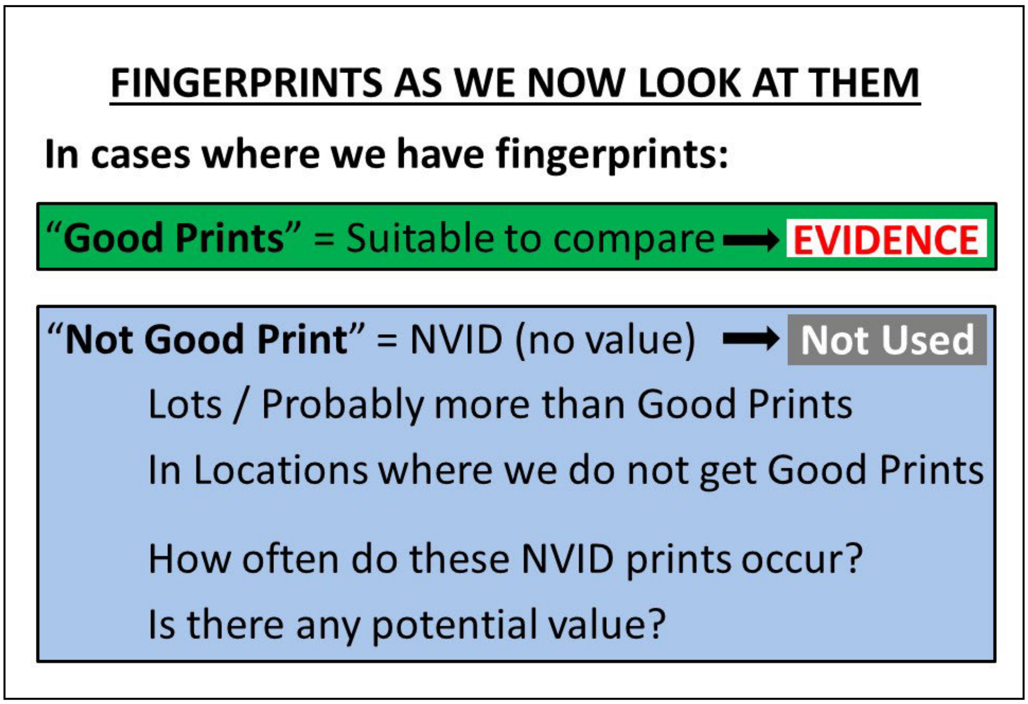


Figure 21. PowerPoint Slide 1 in our initial approach, covering the topic, “fingerprints as we now look at them" and the research questions. Currently, in cases where we have fingerprints there are either “Good Prints,” meaning that they are judged by a fingerprint examiner to be suitable for comparison, or “Not Good Prints,” meaning that they are not suitable for comparison. Good Prints can go forward with comparisons that can result in associative evidence (or exclusions). The Not Good Prints include many prints that are “of no value for identification”: NVID latents. There are lots of these prints – probably more in every case than there are Good Prints. They also occur in locations (e.g. small areas, such as on ammunition or a handgun trigger) where we do not usually get Good Prints. Our research has focused on how often these NVID latents occur and whether they have potential associative value that we might be missing.

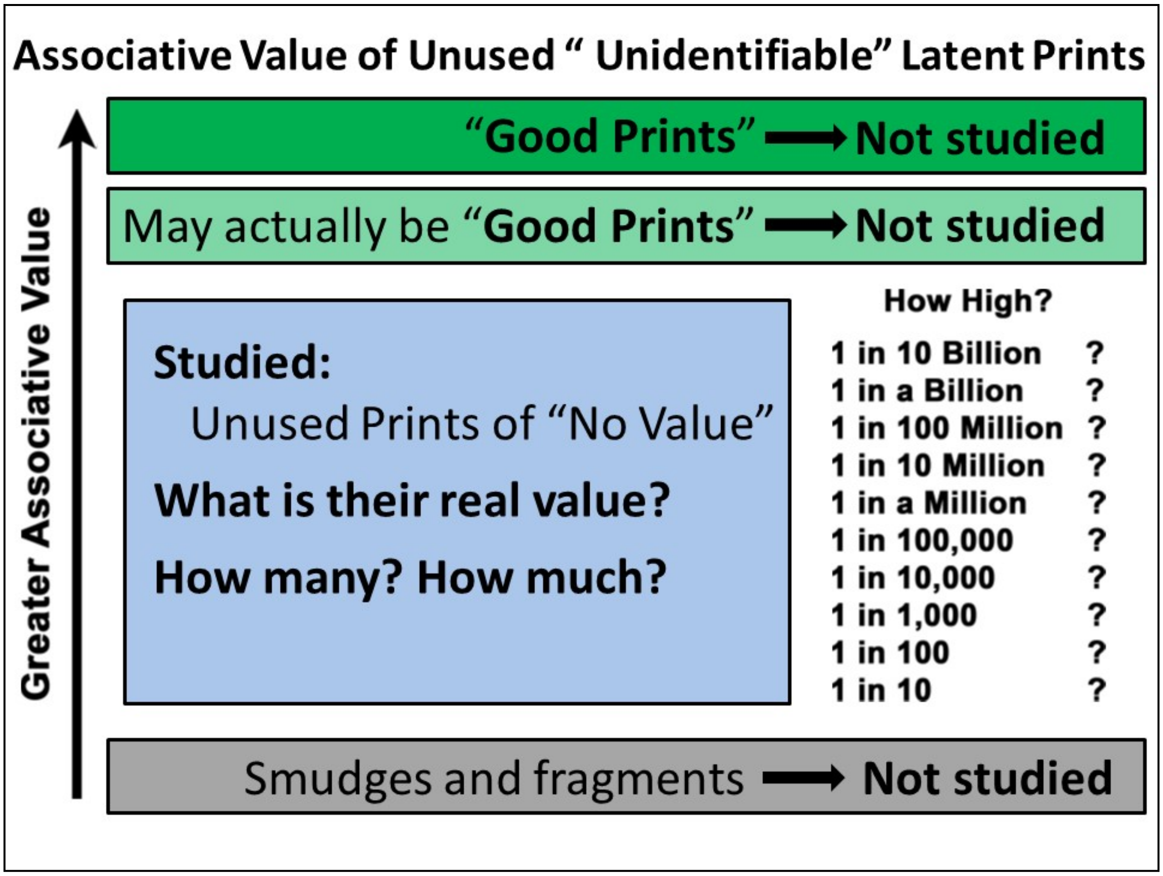


Figure 22. PowerPoint Slide 2 in our initial approach, covering the topic, "approach to the research questions." In this project we did not study "Good Prints" – those that fingerprint examiners would all agree are of value for identification. Because it is sometimes a matter of expert judgement and laboratory policy, there are some prints that would be considered of value by some examiners and laboratories, but not of value by others. This project is not a study about fingerprint examiners or laboratory policies, so prints that might be considered identifiable were not studied. We also did not study finger smudges and very small fragments of prints that had no, or only a very few fingerprint ridge characteristics. Rather, we studied NVID latent prints, those which have some ridge characteristics, but that are currently set aside and unused. What is their real value? How many prints of this type are there and how much is their value? How rare would it be to find one of these prints in the population? 1 in 10 billion? 1 in 10,000? 1 in 10?

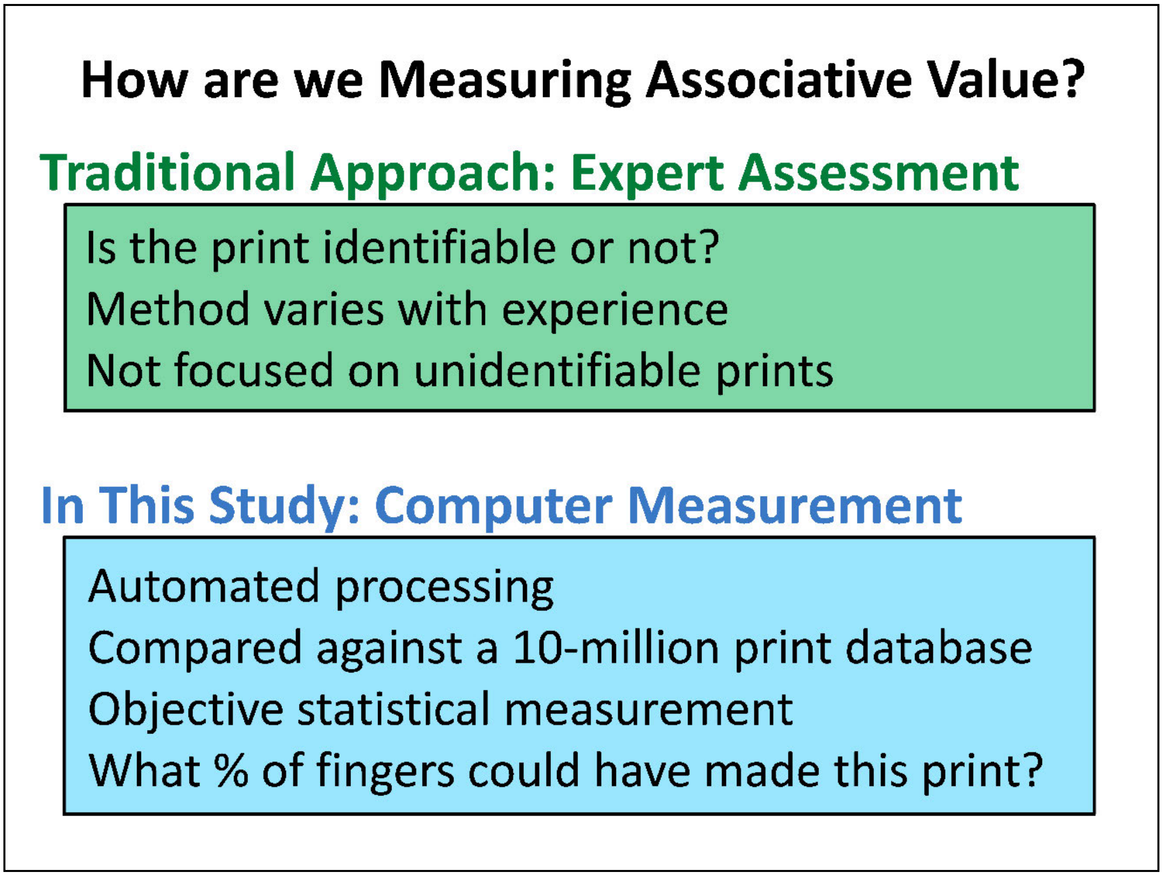


Figure 23. PowerPoint Slide 3 in our initial approach, covering the topic, "how associative value is being determined." The traditional approach to measuring associative value is to use an expert assessment. Experts determine if the latent print is identifiable or not. This method varies with experience and is not focused on the evaluation of unidentifiable (NVID) latent prints. In this study we used computer measurements based on an Automated Fingerprint Identification System (AFIS). Details within the NVID latents were automatically selected, processed and compared against a database of nearly one million prints (963,710) resulting in an objective, statistical measurement of associative value to answer the question, "What percent of fingers could have made this print?"

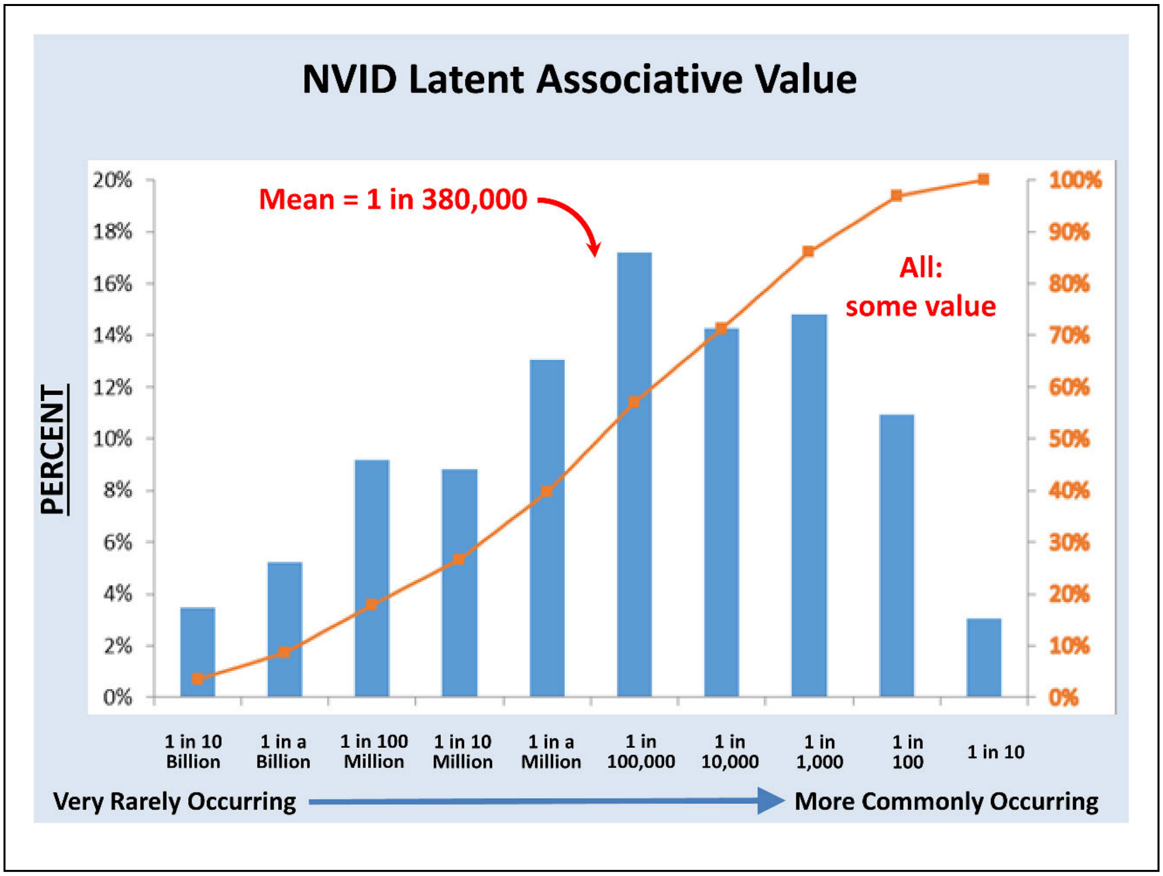


Figure 24. PowerPoint Slide 4 in our initial approach, covering the topic, "chart of Part I research results." This shows the results from our research on the occurrence and associative value of NVID latent prints. Moving from left to right, some prints have a very high associative value. These would be expected to occur only very rarely at random. (For example, about 3.5% of the NVID prints would be expected once in 10 billion fingers.) Others at the far right occur commonly. (For example, about 3% of the NVID prints were be expected as commonly as 1 in 10 individuals.) Reading off the scale to the right, the orange line shows the percentage of NVID prints that are at least as rare as the value on the scale below. On average, the NVID latents showed a value of 1 in 380,000.

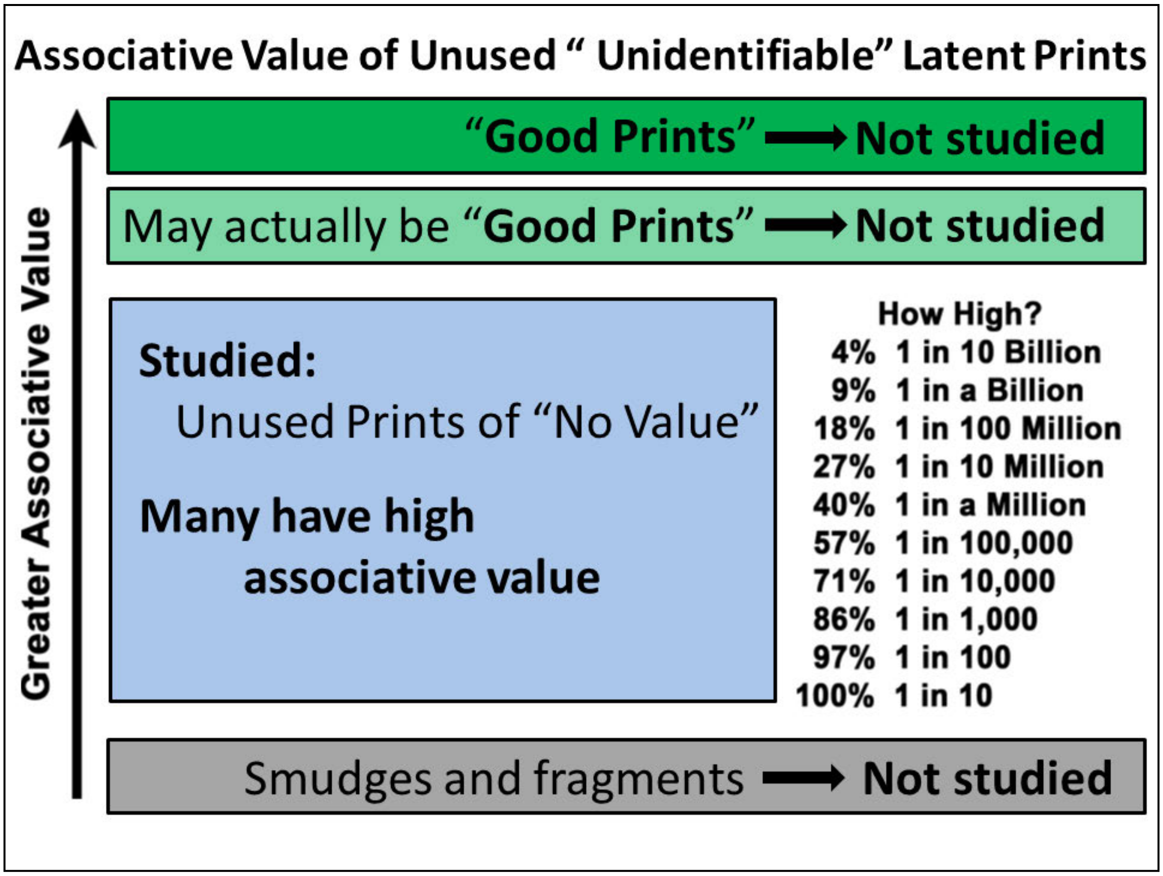


Figure 25. PowerPoint Slide 5 in our initial approach, covering the topic, "explanation of Part I research results." This summarizes the results from our research on the occurrence and associative value of NVID latent prints. There is a range in associative value. Only 4% of NVID latent prints reach values as significant as 1 in 10 billion, but 71% reach 1 in 10,000, while most (97%) showed a value of at least 1 in 100.

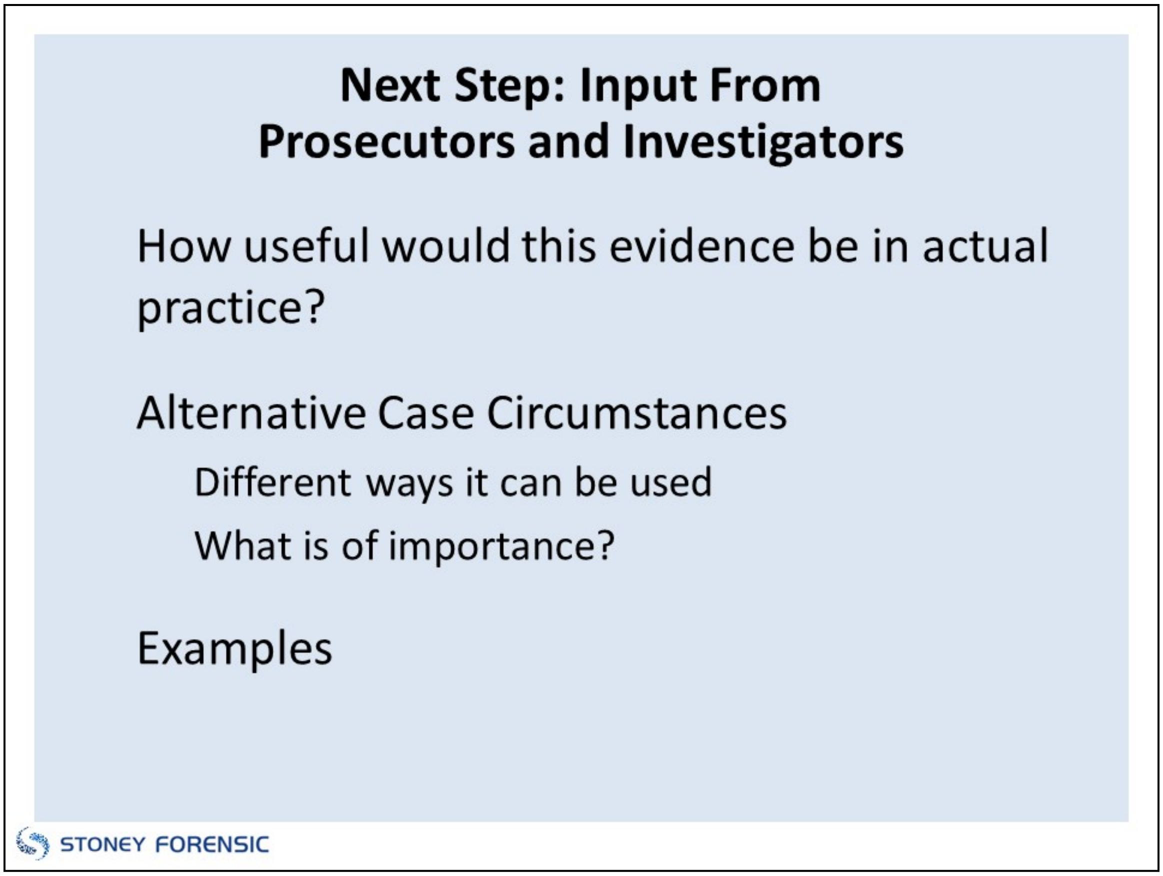


Figure 26. PowerPoint Slide 6 in our initial approach, covering the topic, “next (current) steps.” The next step in this project is to get input from prosecutors and investigators regarding how useful this evidence would be in actual practice. What practical difficulties would you envision? What alternative case circumstances would make this more or less useful? What issues are of importance?

III. B. 4. Final Approach

Our approach evolved to include summaries of the characteristics of NIFMs as well as crime scene illustrations and explanations of the type of associations that would result from NIFM evidence. This approach proceeded in a sequence of 13 steps, some with multiple PowerPoint presentation slides.

1. An introductory slide explaining the purpose of the presentation (presenting the Part 1 research results and soliciting input).

2. A set of 5 slides using a hypothetical crime scene to illustrate fingerprints as we now approach them (using only those prints suitable for definitive identifications or exclusions).

3. A slide presenting a set of key characteristics of NVID prints and the question, "Is there a way to tap this potential?"

4. A slide presenting the research question for Part 1.

5. A slide used to describe the associative value measurements used and contrasting them to traditional expert assessment.

6. A slide showing the numbers of cases and prints in the study.

7. Two slides charting and summarizing Part 1 research results.

8. Two slides contrasting the available evidence when using Fingerprints for Identification vs. using Non-Identifiable Fingermarks for Association.

9. A set of 4 slides explaining how the associative values of the NIFMs could be used as evidence after comparison with a suspect.

10. A slide emphasizing the cumulative effect of many NIFMs at a crime scene.

11. A set of 2 slides showing results with suspect/NIFM associations in explainable locations.

12. A set of 2 slides showing results with suspect/NIFM associations in highly culpable locations.

13. A set of 4 slides summarizing Part 1 of the project and soliciting input.

Figures 27 through 39 show these PowerPoint slides, with captions describing the main explanations and discussion points.

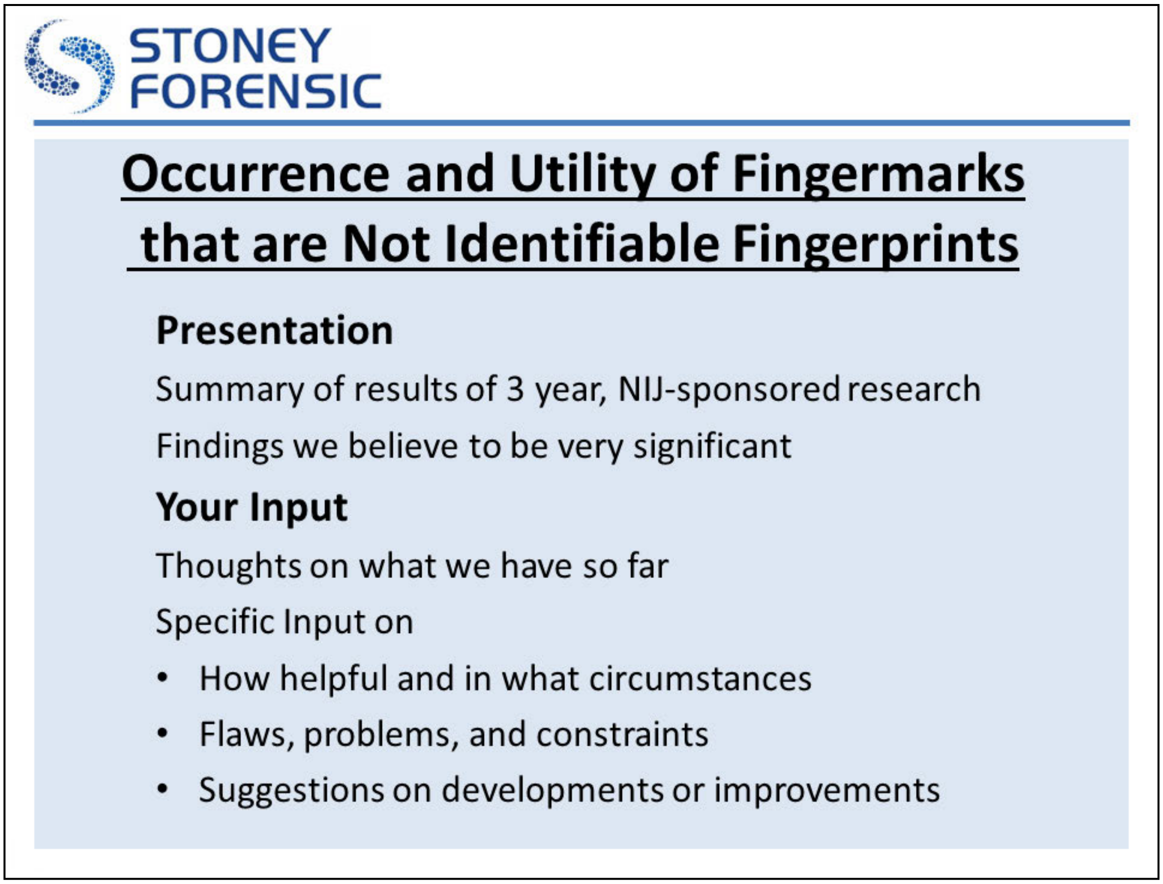


Figure 27. PowerPoint Slide 1, an introductory slide explaining the purpose of the presentation. The presentation is a part of a three-year, NIJ-sponsored research project exploring the occurrence and utility of fingermarks that are not identifiable fingerprints. The presentation summarizes the results from Part 1 of this project, which we believe to be very significant. The next step of the research, and the purpose of this presentation, is to get your input. We are soliciting your thoughts on what we have done so far and your view on how helpful this type of evidence might be and in what circumstances. Importantly, this includes your views on any flaws in the approach, problems that could be encountered in the use of this type of evidence and constraints that there might be. Any suggestions for further development or improvements are very welcome.

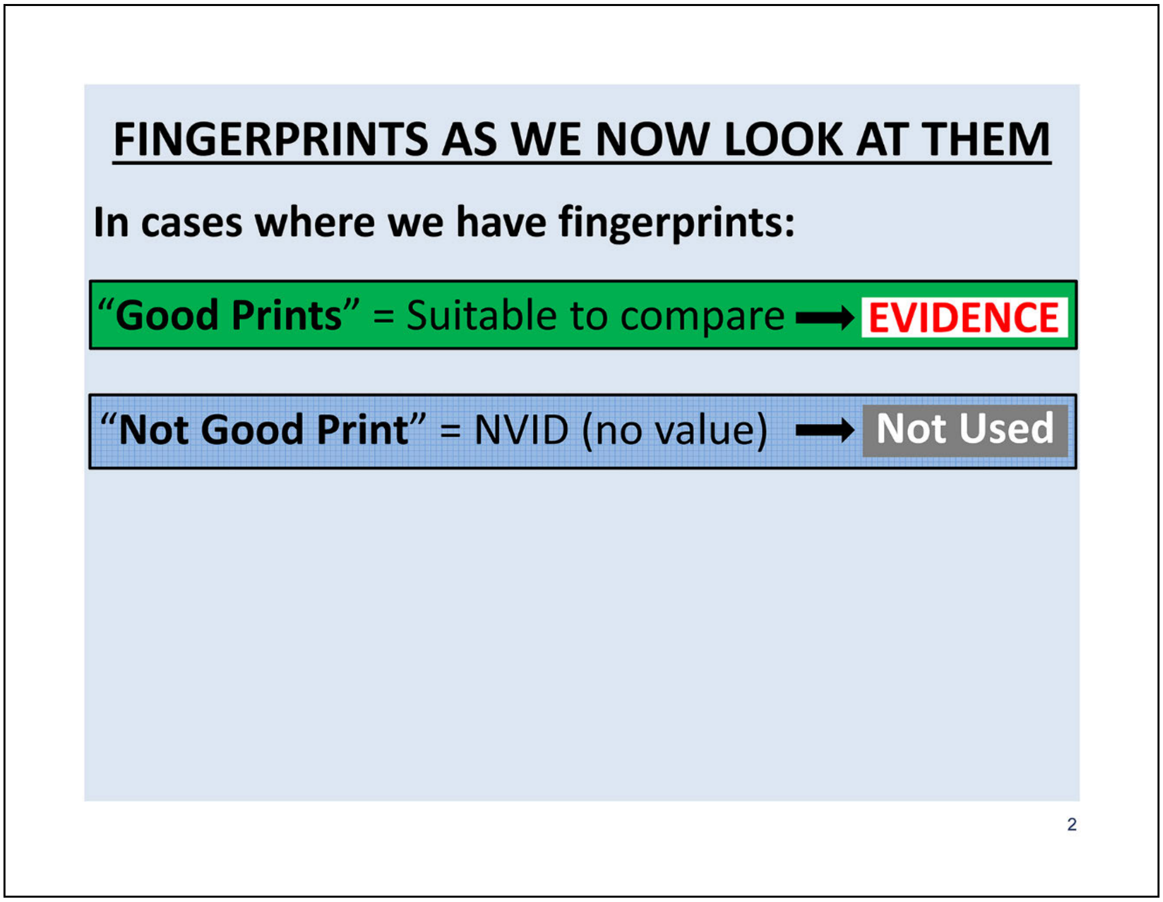


Figure 28A. First slide in a set of 5 using a hypothetical crime scene to illustrate fingerprints as we now approach them (using only those prints suitable for definitive identifications or exclusions). Currently, in cases where we have fingerprints there are either "Good Prints," meaning that they are judged by a fingerprint examiner to be suitable comparison, or "Not Good Prints," meaning that they are not suitable for comparison. Good Prints can go forward with comparisons that can result in associative evidence (or exclusions). The Not Good Prints include many prints that are "of no value for identification": NVID latents. There are lots of these prints – probably more in every case than there are Good Prints. They also occur in locations (e.g. small areas, such as on ammunition or a handgun trigger) where we do not usually get Good Prints. Our research has focused on how often these NVID latents occur and whether they have potential associative value that we might be missing.

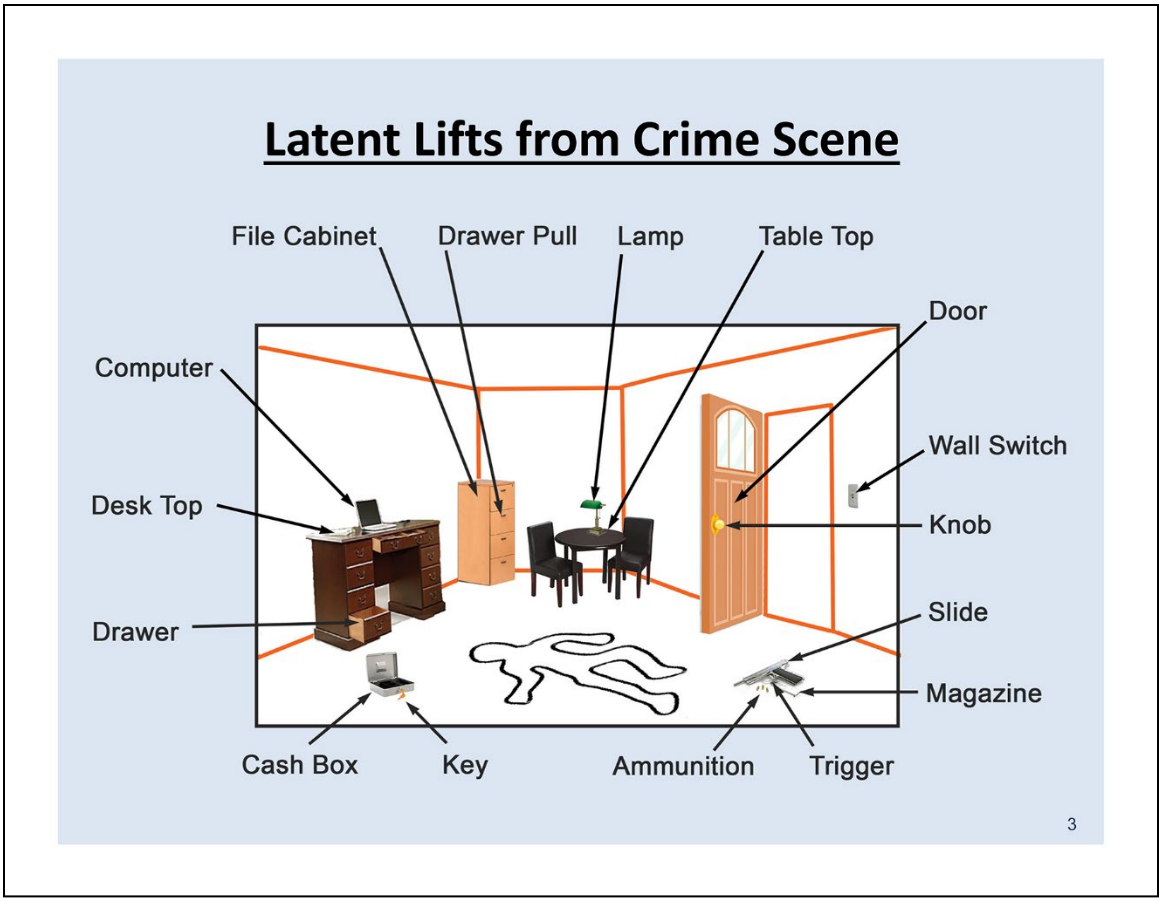


Figure 28B. Second slide in a set of 5 using a hypothetical crime scene to illustrate fingerprints as we now approach them (using only those prints suitable for definitive identifications or exclusions). This is a hypothetical murder scene that we will be using in this presentation to contrast fingerprint evidence with associative evidence that might result from non-identifiable fingermarks. The occupant of a small office with a client seating area was shot and a handgun was found at the scene. A cashbox (now empty) had been removed from a desk drawer and opened with a key. A total of 41 latent prints were recovered from the crime scene.

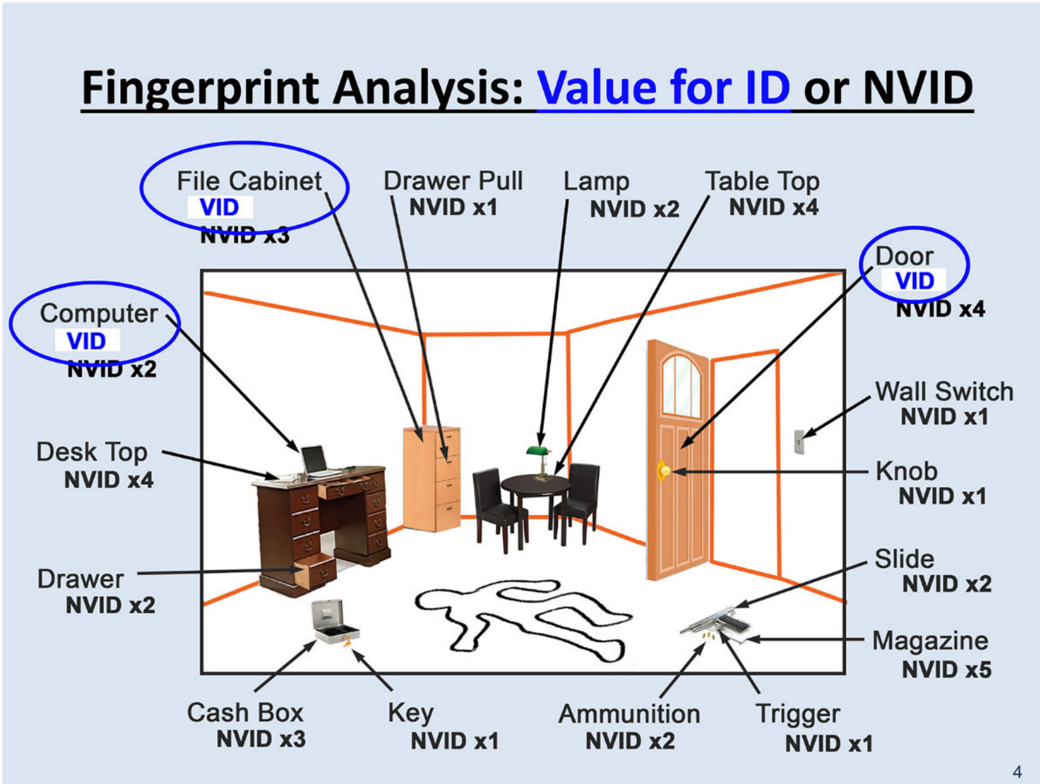


Figure 28C. Third slide in a set of 5 using a hypothetical crime scene to illustrate fingerprints as we now approach them (using only those prints suitable for definitive identifications or exclusions). Following the current approach of screening these latent prints based on expert evaluations, three of the 41 prints are assessed to be of value for identification (VID). The remaining 38 are NVID and set aside.

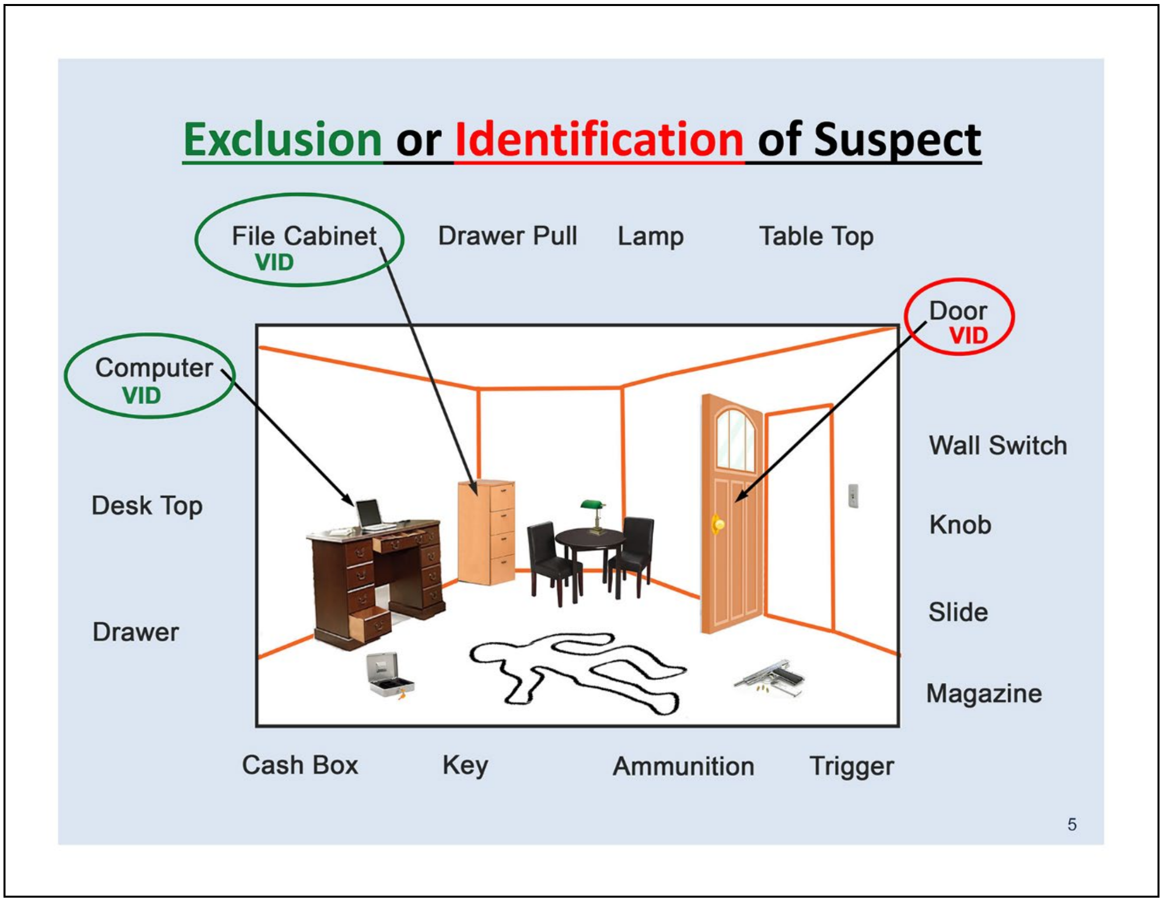


Figure 28D. Fourth slide in a set of 5 using a hypothetical crime scene to illustrate fingerprints as we now approach them (using only those prints suitable for definitive identifications or exclusions). When a suspect is developed the three prints that are of value for identification are compared to the known fingerprints of the suspect, resulting in exclusions or identifications. Here we have indicated one result: the suspect being excluded as having made the fingerprints on the filing cabinet and the computer (VID shown in green), while being identified to the fingerprint on the outside of the door (VID shown in red).

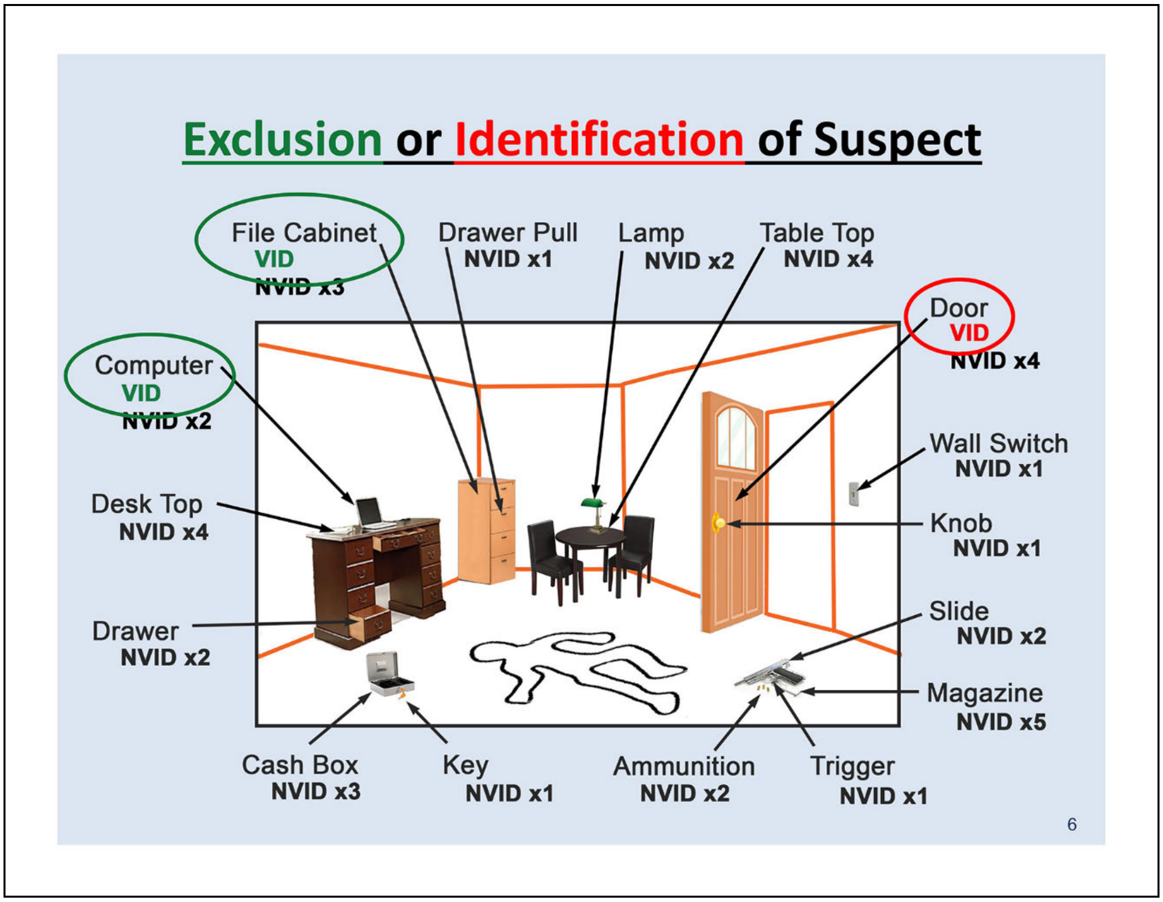


Figure 28E. Fifth slide in a set of 5 using a hypothetical crime scene to illustrate fingerprints as we now approach them (using only those prints suitable for definitive identifications or exclusions). The other 38 NVID latent prints have been set aside and are unused. They are of no value for opinion evidence for identification or for exclusion. But what about the utility of these prints to provide additional evidence either supporting or refuting this suspect's involvement in the crime?

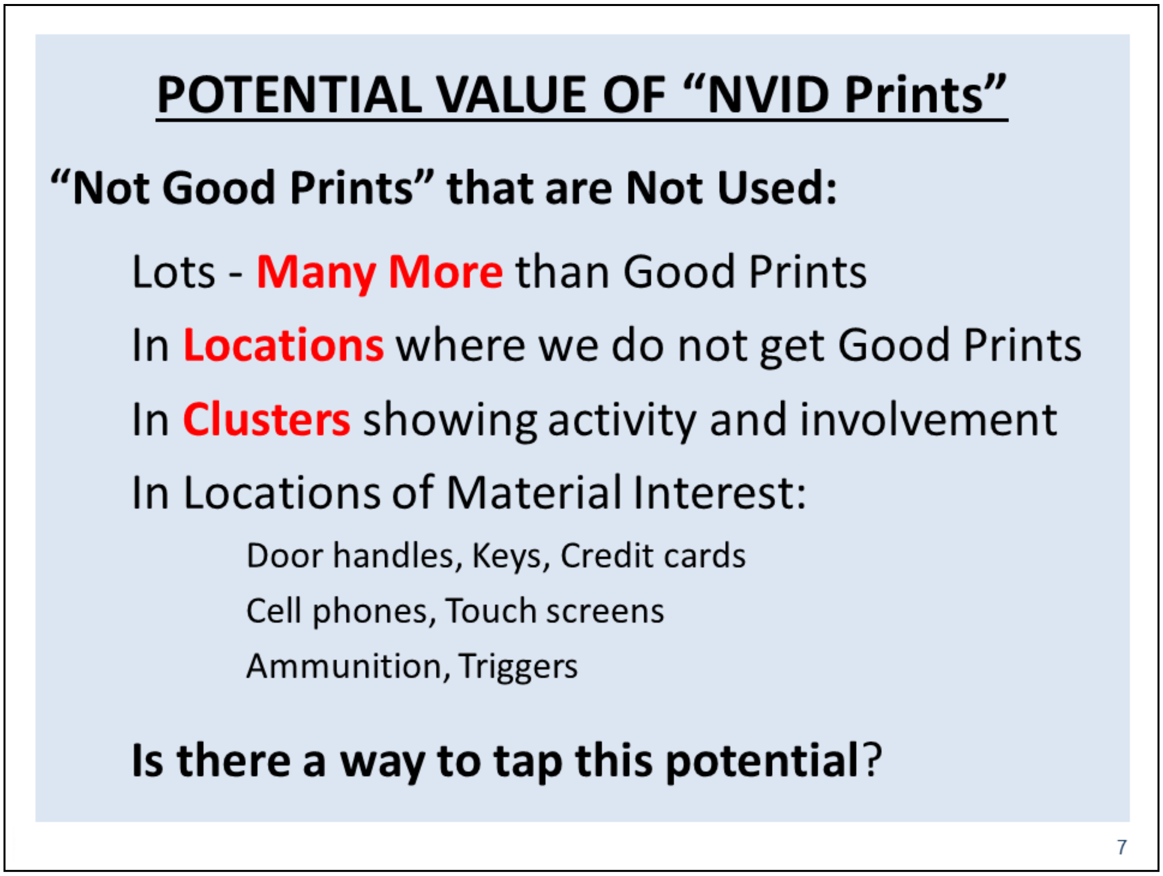


Figure 29. PowerPoint Slide covering the topic, "potential value of 'NVID' prints." There are lots of these "not good prints," that are not used – many more than the good (identifiable) prints. Many are found in locations where it is very uncommon to find good prints. They can be found in clusters where, if associated to an individual, they could show activity and involvement. They are also often found in locations of material interest such as door handles, keys, and credit cards; on cell phones and touch screens; on ammunition and triggers.

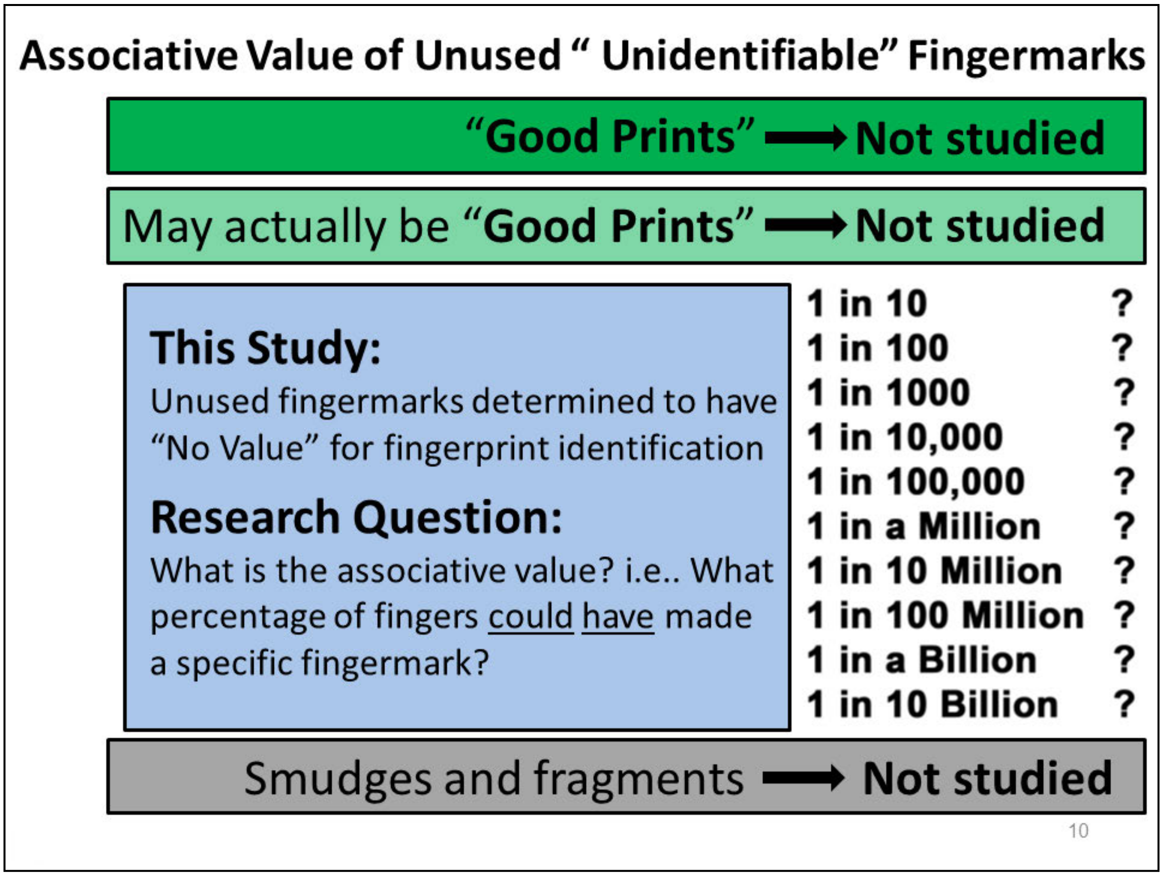


Figure 30. PowerPoint Slide covering the topic, "associative value of unused 'unidentifiable' fingermarks." In this project we studied unused fingermarks that were determined to be of "No Value" for fingerprint identification. We did not study "Good Prints" – those that fingerprint examiners would all agree are of value for identification. Because it is sometimes a matter of expert judgement and laboratory policy, there are some prints that would be considered of value by some examiners and laboratories, but not of value by others. This project is not a study about fingerprint examiners or laboratory policies, so prints that might be considered identifiable were not studied. We also did not study finger smudges and very small fragments of prints that had no, or only a very few fingerprint ridge characteristics. Rather, we studied NVID latent print which had some ridge characteristics, but that are currently set aside and unused. What is their real value? How many prints of this type are there and how much is their value? How rare would it be to find one of these prints in the population? 1 in 10 billion? 1 in 10,000? 1 in 10?

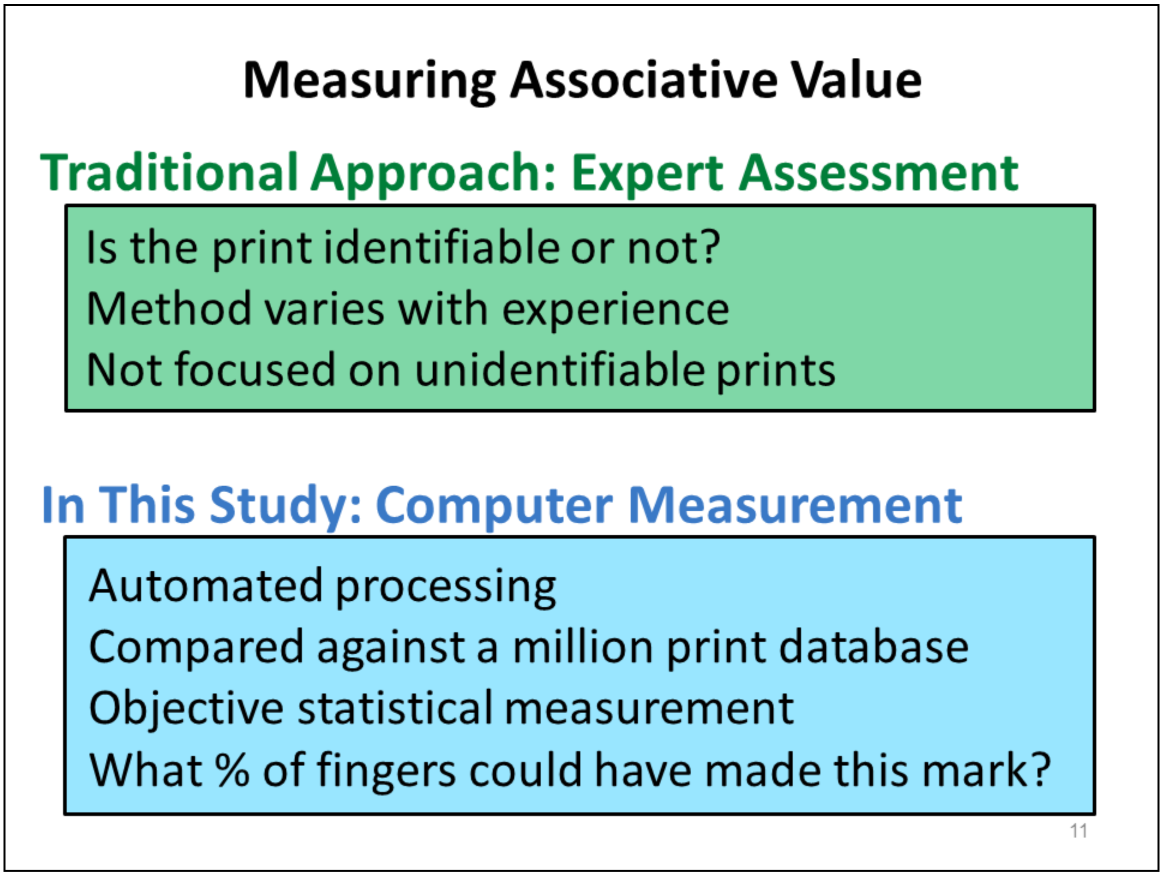


Figure 31. PowerPoint Slide covering the topic, "measuring associative value." The traditional approach to measuring associative value is to use an expert assessment. Experts determine if the latent print is identifiable or not. This method varies with experience and is not focused on the evaluation of unidentifiable (NVID) latent prints. In this study we used computer measurements based on an Automated Fingerprint Identification System (AFIS). Details within the NVID latents were automatically selected, processed and compared against a database of nearly one million prints (963,710), resulting in an objective statistical measurement of associative value to answer the question, "What percent of fingers could have made this print?"

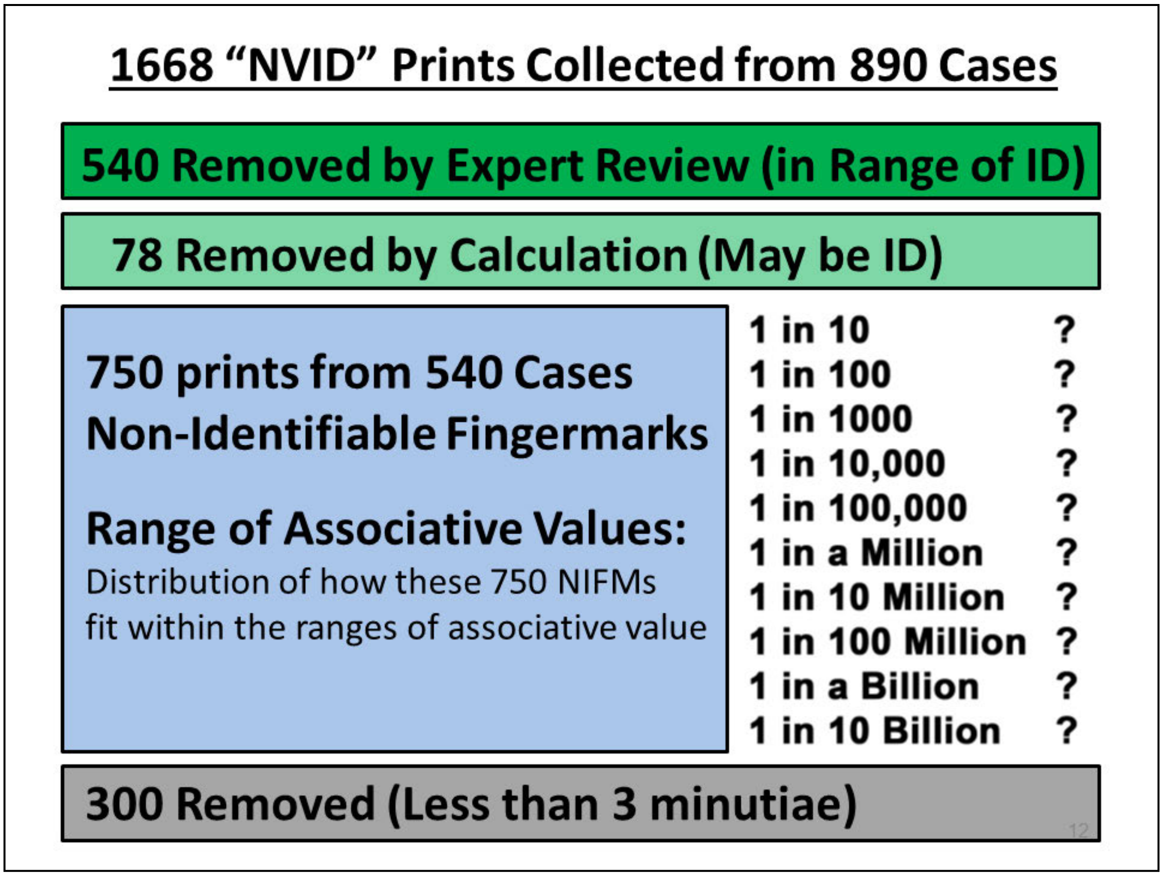


Figure 32. PowerPoint Slide showing the numbers of cases and prints in the study. A total of 1668 fingermark images, representing 890 cases, were collected from 9 jurisdictions within the USA. Expert review resulted in removal of 540 of the marks (32.4%) on the basis that they were potentially identifiable. Another 78 marks were removed as calculations showed associative values indicating that they might be identifiable. At the other extreme, 300 marks were removed as failing to meet the minimum requirement of 3 clear and reliable minutiae with clear relationship to each other within the ridge structure. This left 750 non-identifiable fingermarks (NIFMs) whose associative values were calculated.

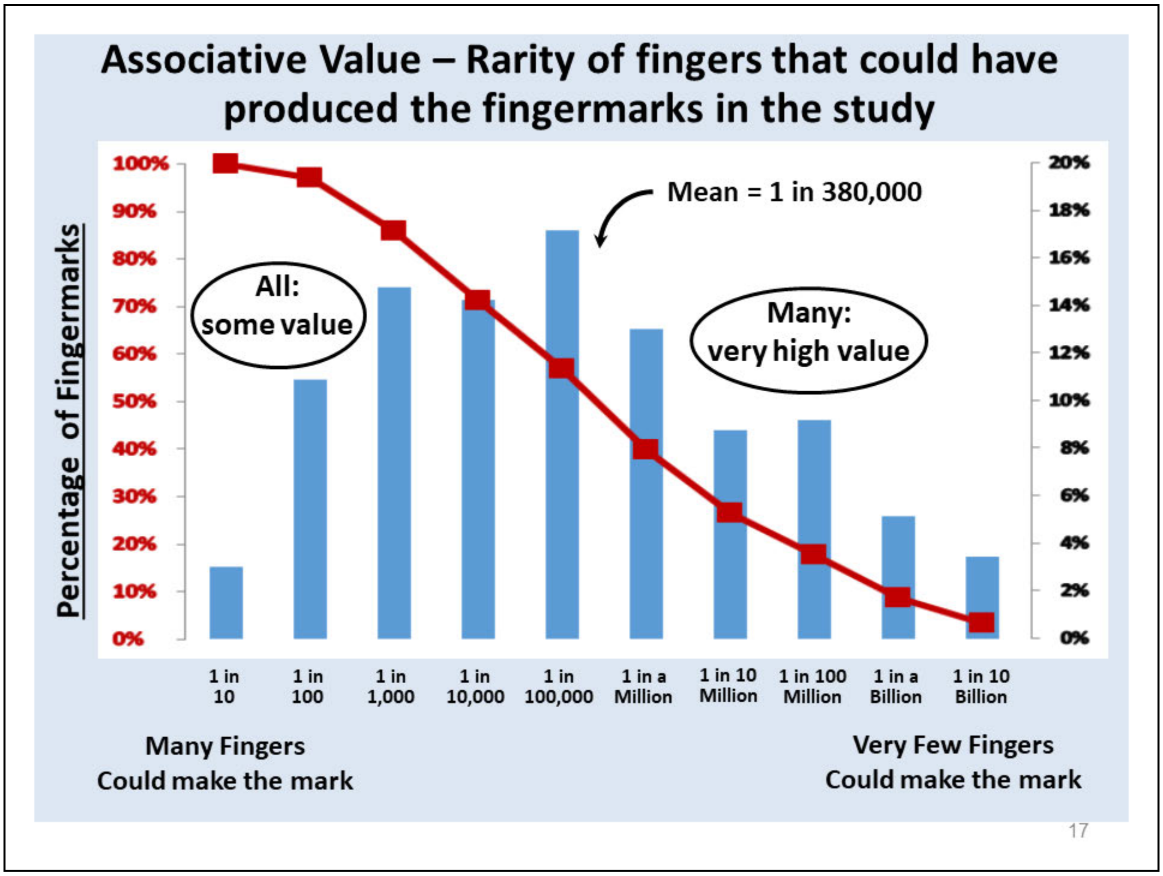


Figure 33A. First of two slides charting and summarizing Part 1 research results. This is a chart of the associative value measurements for the 750 NIFMs meeting the program requirements. The horizontal scale shows the expected frequency of occurrence of the ridge detail expressed as the number of fingers that could have made the mark. At the left end (starting 1 in 10, 1 in 100....), many fingers could have made the mark. Moving to the right end, very few fingers could have made the mark. The blue bars, following the vertical scale on the right, show the percentages of the NIFMs within each level of rarity. The red line follows the vertical scale on the left and shows the percentages of NIFMs that are at least as rare as a given level. All of the NIFMs have some associative value, and many have very high associative value. The mean level of rarity seen among the marks was 1 in 380,000.

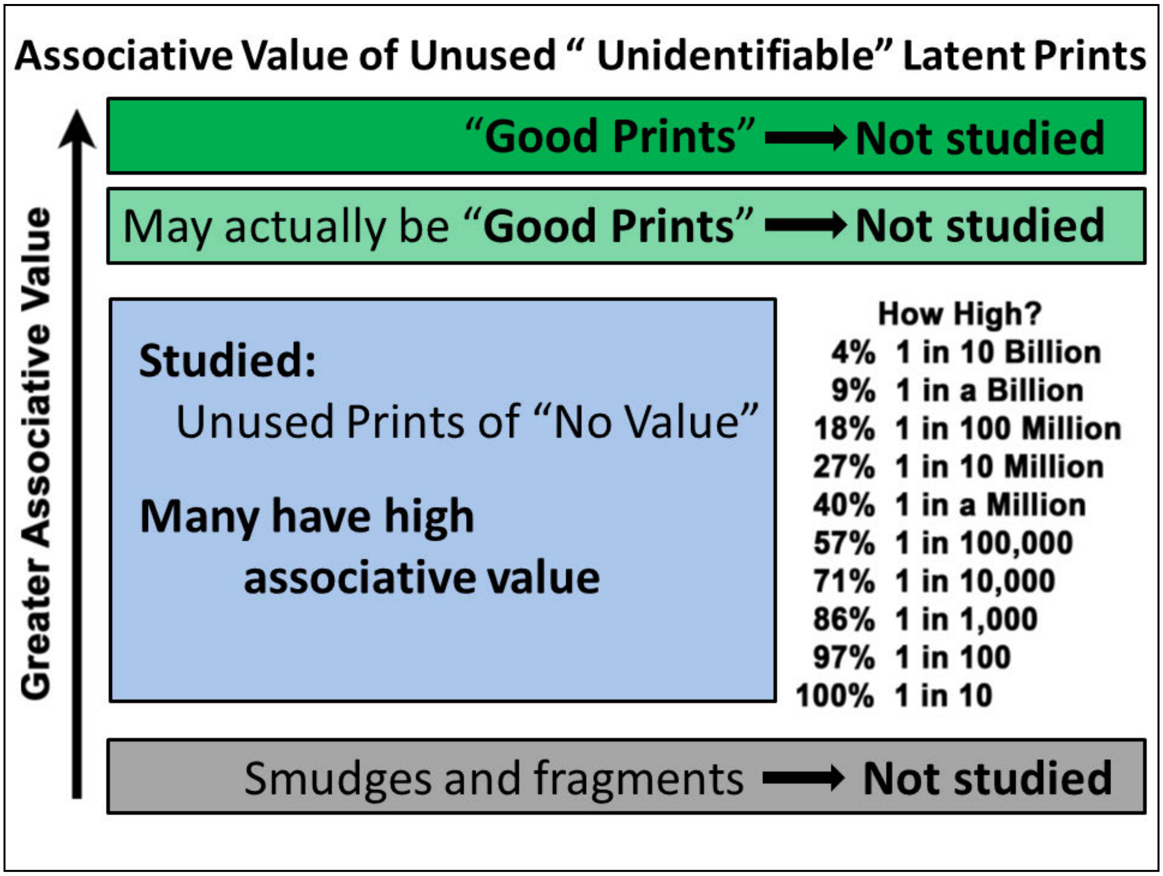
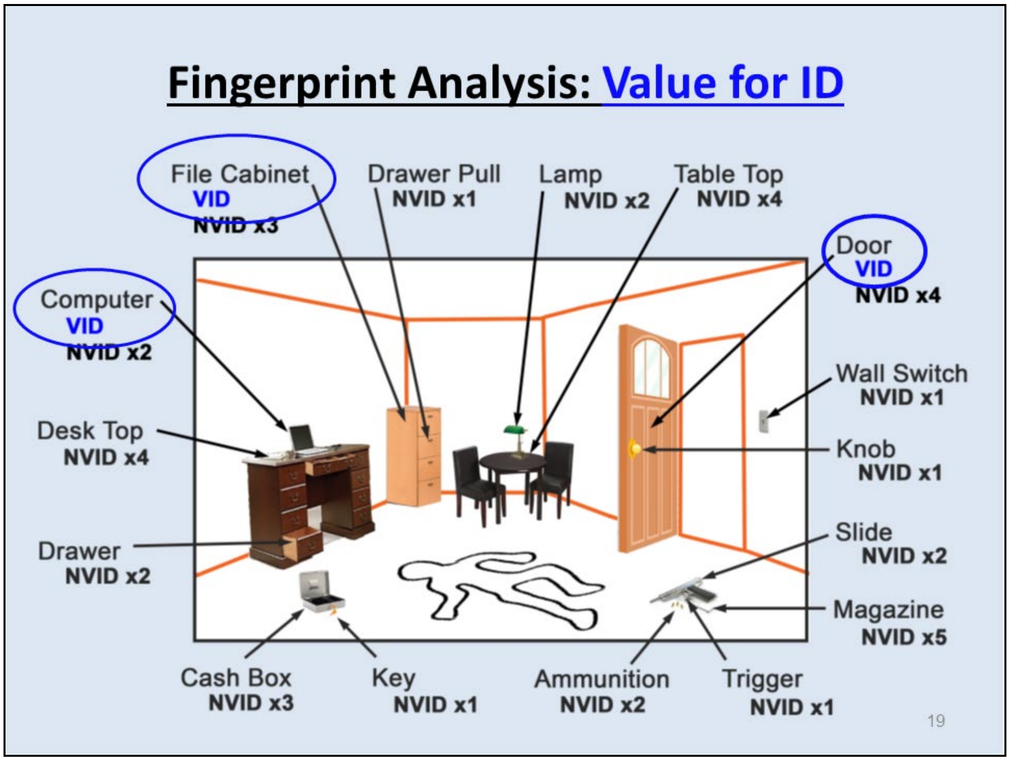


Figure 33B. Second of two slides charting and summarizing Part 1 research results. This is a summary of the results from our research on the occurrence and associative value of NIFMs. There is a range in associative value. Only 4% of NIFMs reach values as significant as 1 in 10 billion, but 77% reach 1 in 10,000, while most (97%) showed a value of at least 1 in 100.



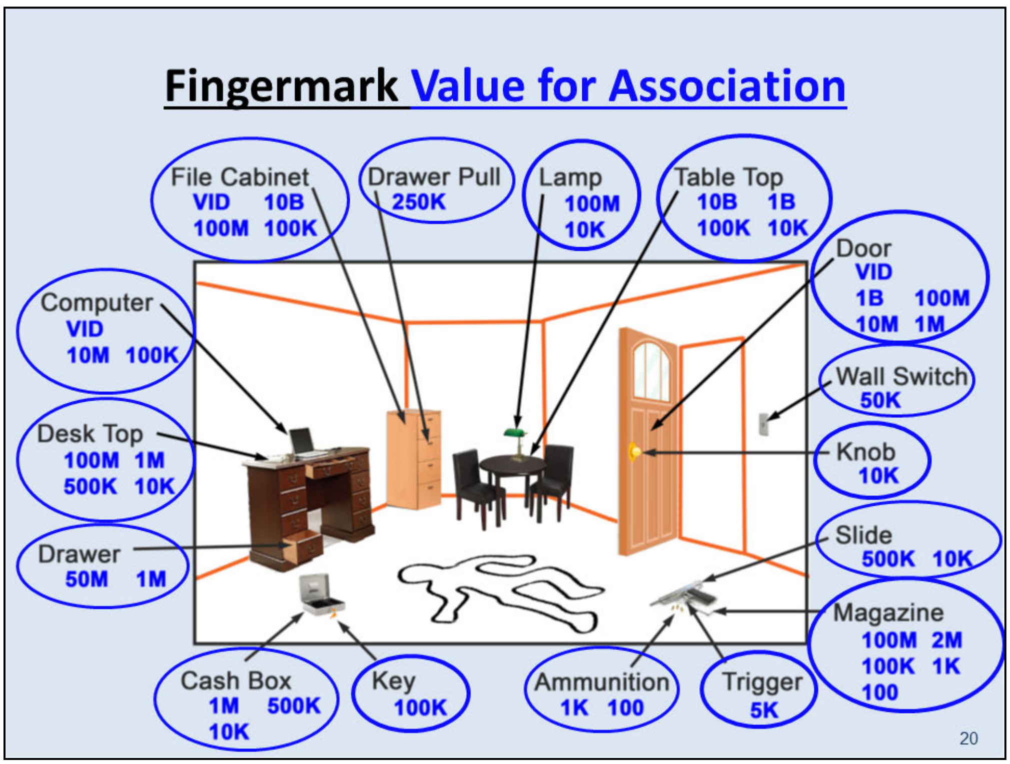
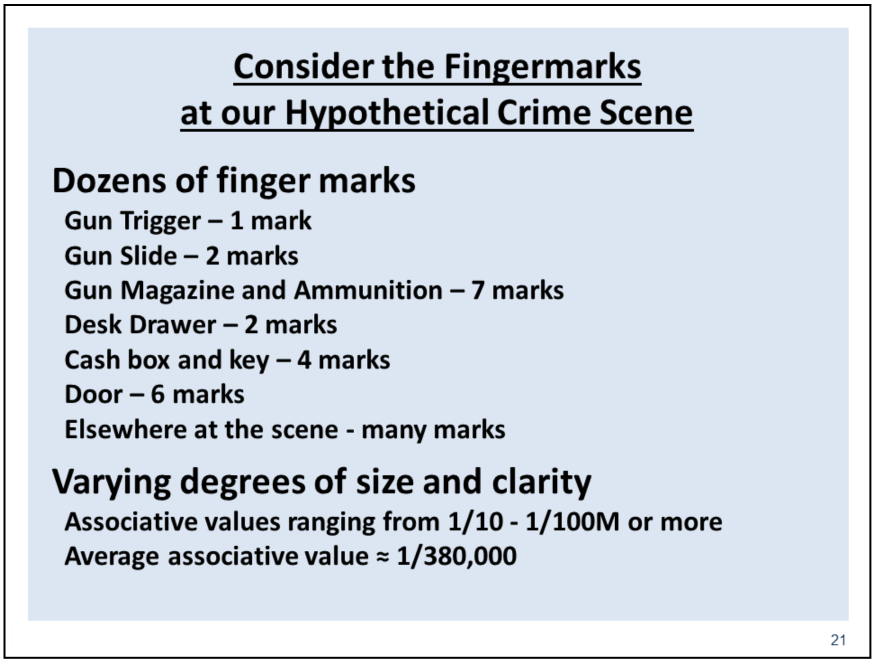


Figure 34. A contrast between the available evidence when using fingerprints for identification (top) as opposed to using Non-Identifiable Fingermarks for association (bottom). The NIFMs augment the existing evidence, giving potential for large numbers of less definitive associations.



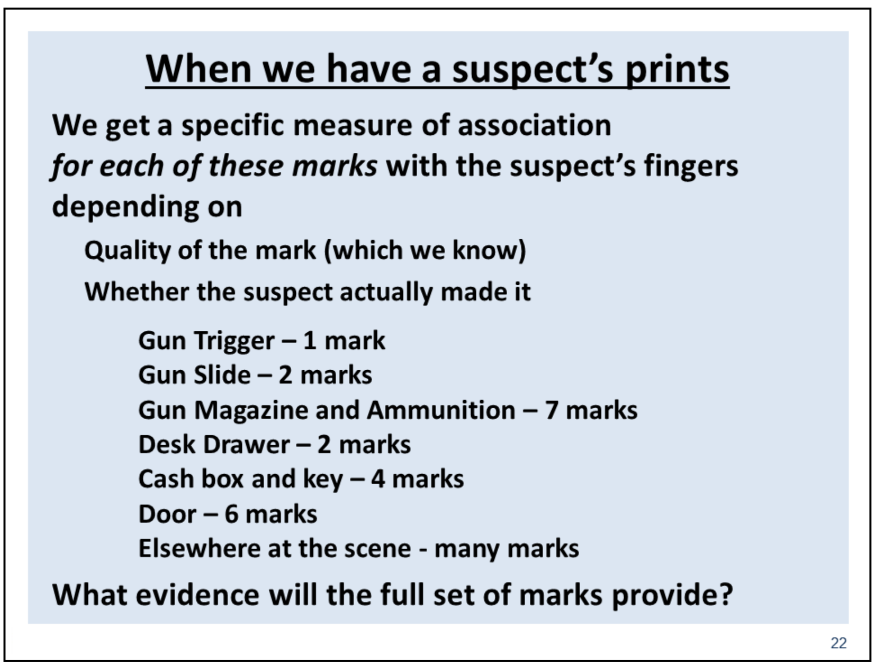
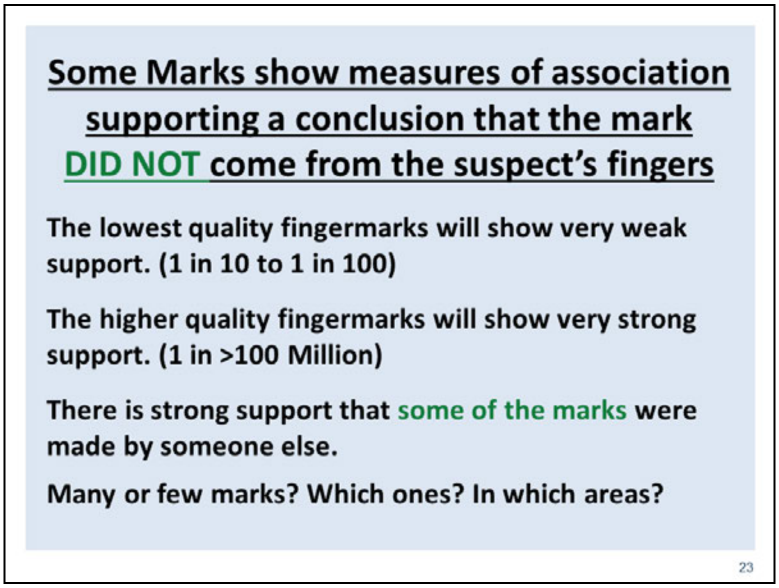


Figure 35A. First two of set of 4 slides explaining how the associative values of the NIFMs could be used as evidence after comparison with a suspect. Top: Consider the fingermarks at our hypothetical crime scene. There are dozens of fingermarks, including those on the gun (trigger, slide, magazine, ammunition), those from the desk drawer that held the cashbox, those on the cashbox and key, and those on the door. The marks have varying degrees of size, clarity and ridge detail. Bottom: When we have a suspect's prints we will get a specific measure of association for each of these marks with the suspect's fingers, depending on the quality of the mark (which we know) and whether the suspect actually made the mark. What evidence will the full set of marks provide?



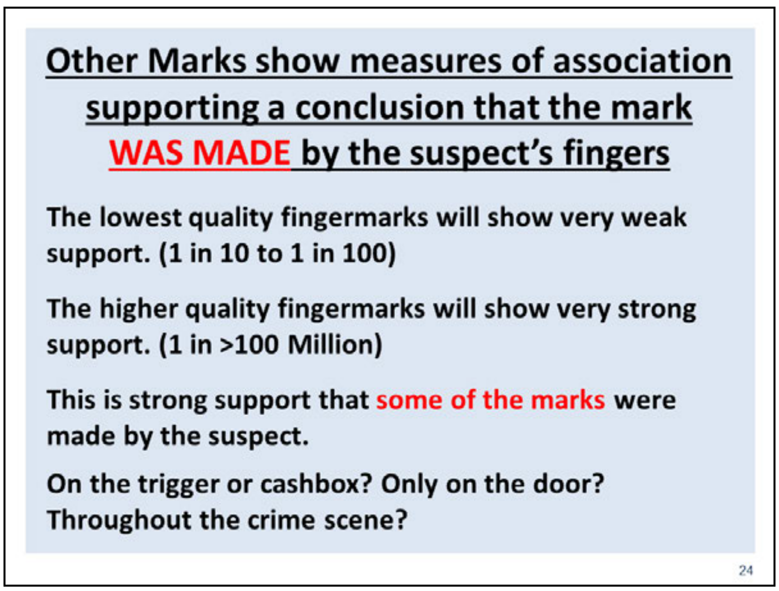


Figure 35B. Last two of set of 4 slides explaining how the associative values of the NIFMs could be used as evidence after comparison with a suspect. Top: Some marks will show measures of association supporting a conclusion that the mark DID NOT come from the suspect's fingers. The lowest quality fingermarks will show very weak support (1 in 10 to 1 in 100). The higher quality fingermarks will show very strong support (rarer than 1 in 100 million). There is strong support that some of the marks were made by someone else. Will there be many or few marks? Which ones? In which areas? Bottom: Other marks will show measures of association supporting a conclusion that the mark WAS MADE by one of the suspect's fingers. As before, the lowest quality fingermarks will show very weak support (1 in 10 to 1 in 100). The higher quality fingermarks will show very strong support (rarer than 1 in 100 million). There is strong support that some of the marks were made by the suspect. Are they in places that are highly culpable, such as on the gun trigger or the cashbox? Or are they only on the door? Are they throughout the crime scene or only in certain areas?

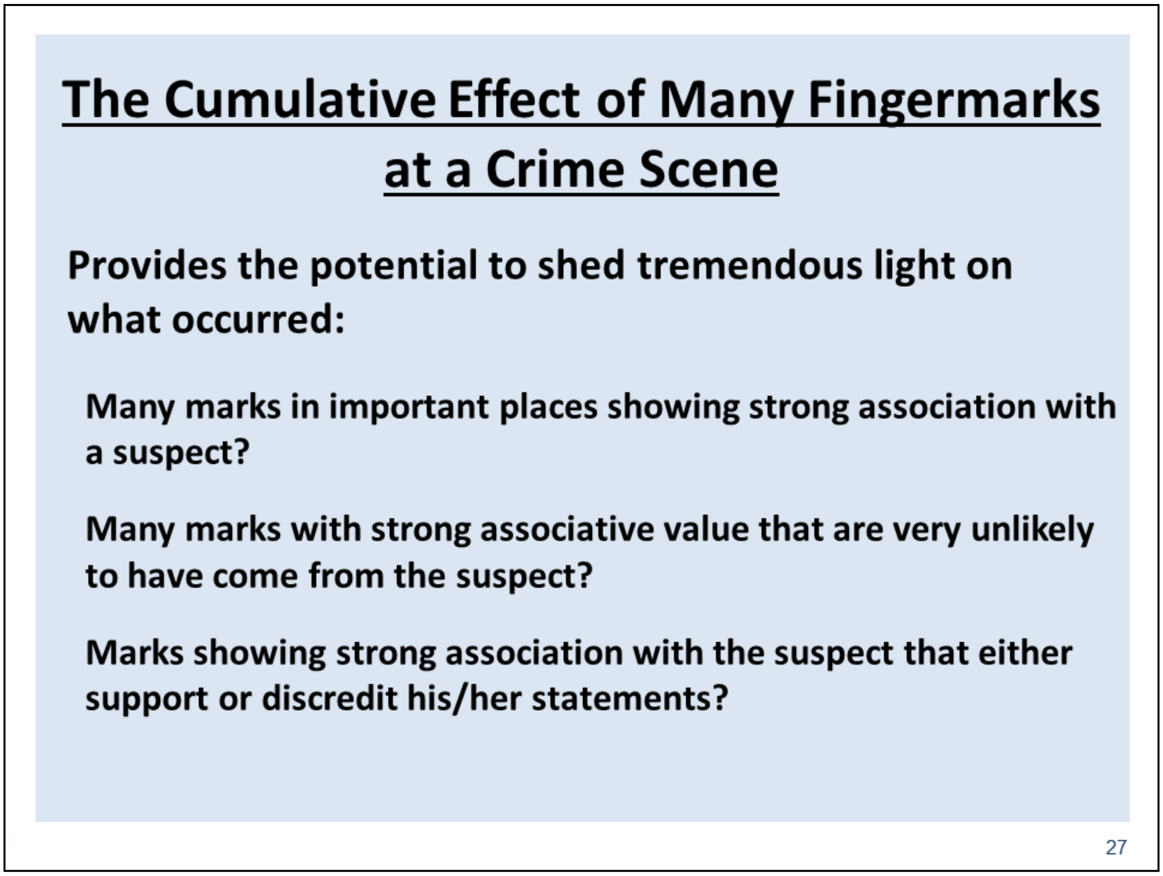


Figure 36. PowerPoint slide covering the topic "the cumulative effect of many fingermarks at a crime scene.” The cumulative effect of many fingermarks at a crime scene provides the potential to shed tremendous light on what actually occurred. Are there many marks in important places showing strong association with a suspect? Conversely, are there many marks with strong associative value that are very unlikely to have come from the suspect? Are there marks showing strong association with the suspect that either support or discredit his/her statements about activity at the scene?

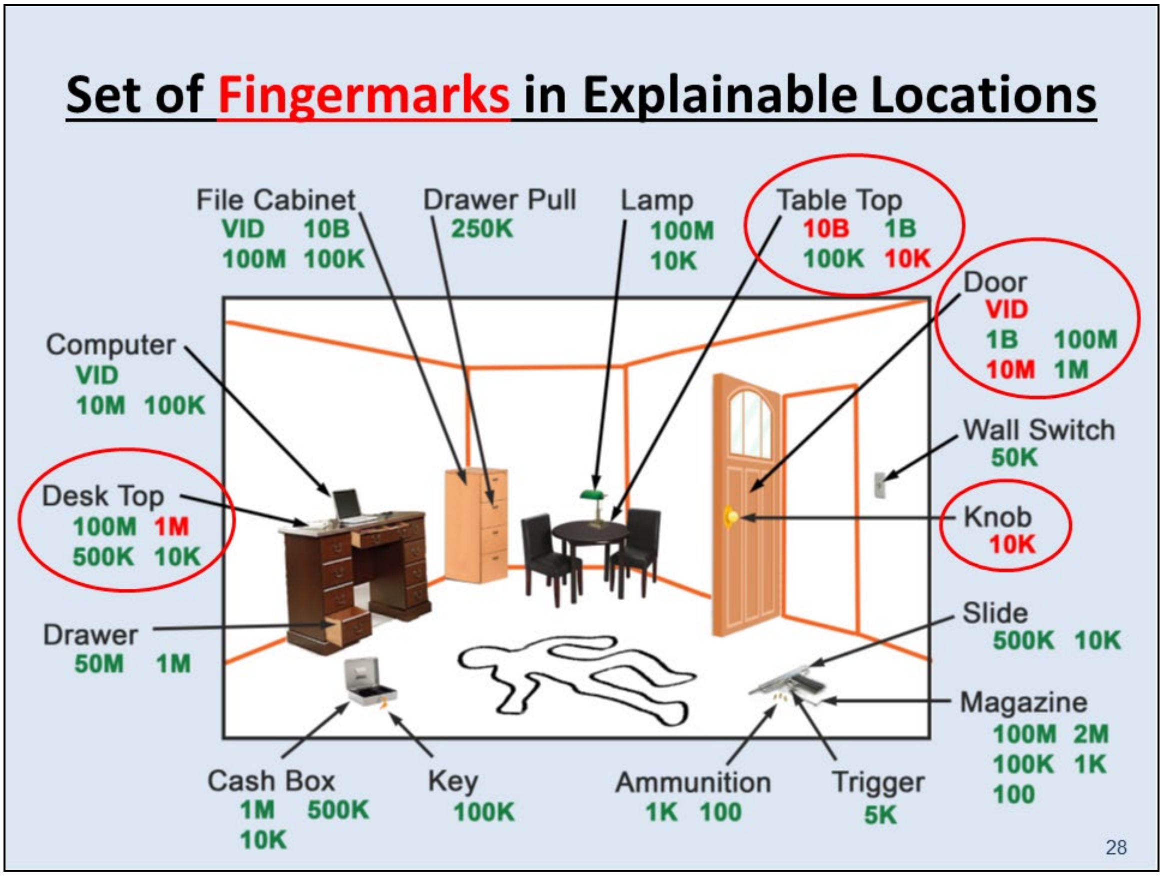


Figure 37. A scenario that shows sets of fingermarks associated with the suspect in explainable locations. There is strong support (including one fingerprint identification) that the suspect touched the door, and also support for touching the door knob, the desk top and the table. The other areas show marks that are very likely from someone else, including the cash box, key and weapon. What does this suggest? How does it fit with suspect's story or witness statements? How does it fit with other evidence?

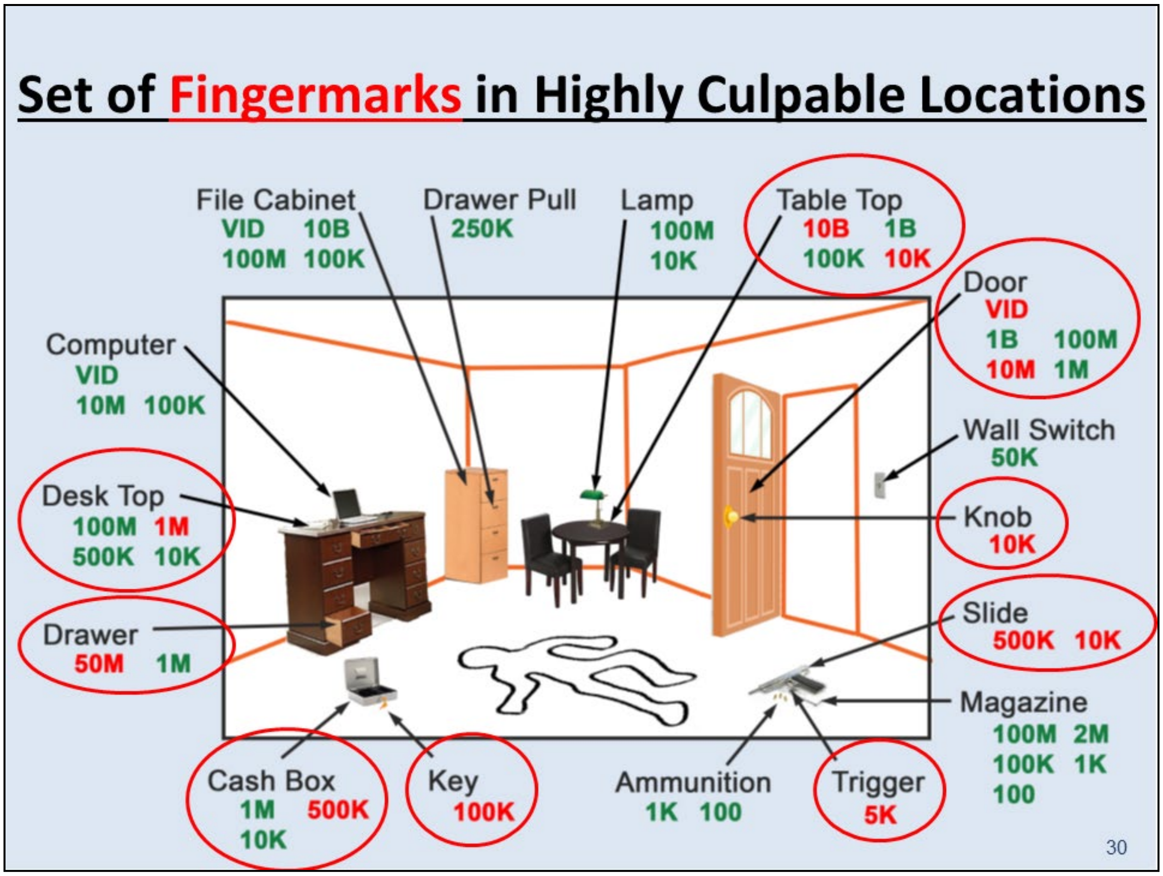


Figure 38. A scenario that shows a set of fingermarks associated with the suspect in highly culpable locations. There is strong support (including one fingerprint identification) that the suspect touched the door, and also support for touching the door knob, the desk drawer that held the cash box, the cash box itself and its key, the handgun slide, the handgun trigger and other areas in the office. There are some areas with marks that are very likely from someone else, including the drawer, the cash box, the handgun magazine and the handgun ammunition. What does this suggest? How does it fit with suspect's story or witness statements? How does it fit with other evidence? It looks like he was very active at the scene and that he opened the cash box. It doesn't look like he loaded the gun, but it sure looks like he fired it.

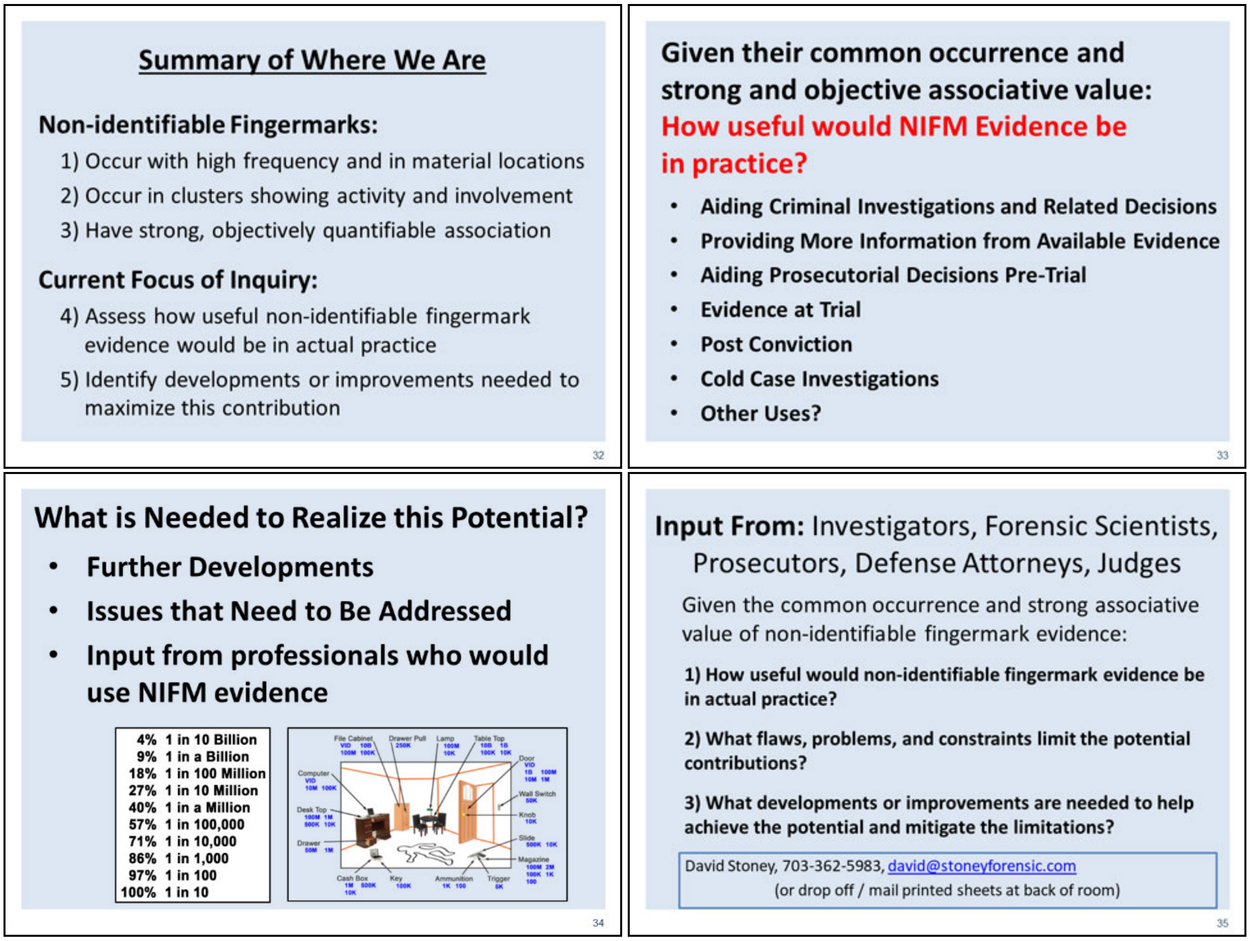


Figure 39. A set of 4 slides summarizing Part 1 of the project and soliciting input. These slides review the findings and pose the question of how useful NIFM evidence would be in practice, soliciting input into (1) the nature of this utility, (2) any flaws, problems or constraints that would limit potential contributions, and (3) what developments or improvements are needed to achieve potential and mitigate limitations.

III. B. 5. Consolidation and Interpretation

A considerable amount of effort was spent in the consolidation and interpretation of the responses obtained from the broad range of individuals who participated in the assessment of the potential of NIFM evidence. As we obtained additional input, our initial assessments were shared and reviewed with others who provided input during presentations, discussions and follow-up interviews.

We believe that an accurate consolidated assessment has been the result. However, this assessment is subjective and is necessarily affected by limitations in the researchers' abilities. It is none-the-less a meaningful and broadly representative foundation to begin the wider consideration of NIFM evidence. Our expectation is that the assessment will be further refined and improved by reactions to this work and its publication, continuing professional consideration of the possibilities and limitations of NIFM evidence, and further research.

The results are presented in the two sections that follow. The first section focuses on the characteristics of NIFM evidence and its materiality. NIFM evidence is compared to other types of evidence, emphasizing characteristics that make it both (1) clearly distinct from conventional fingerprint evidence, and (2) exceptional among less definitive classes of evidence. The second section focuses on assessments of potential utility of NIFM evidence in different stages in the criminal justice process: aiding of investigations and prosecutorial decision-making, evidence at trial, in post-conviction reviews and as applied to special investigations.

III. C. Results: The Character of Non-Identifiable Fingermark Evidence

A Non-Identifiable Fingermark (NIFM) is a mark containing reliable friction ridge detail with a combination of minutiae in sequence that is insufficient for identification using the fingerprint ACE-V process. This section of the results focuses on the character of NIFM evidence.

III. C. 1. NIFM Associations are Distinct from Fingerprint Identification

An important initial finding is that there is a fundamental distinction between NIFM association evidence and fingerprint identification evidence as currently conceived. Current fingerprint examination practices only result in associations when there is an identification. Identifications are long-established, universally accepted, subjective decisions made after performing a well-articulated series of documented observations and assessments (the application of ACE-V).[1] Identification decisions have a very high threshold of associative value, with nearly negligible rates of false association when appropriate expert qualifications and laboratory controls are in place.

NIFM association evidence does not arise through the expert-dependent fingerprint ACE-V process and latent fingerprint examiners do not have an experiential basis to evaluate these prints. Aspects of ACE-V could certainly be applied (such as expert assessment of the presence and reliability of friction ridge detail in the Analysis phase), but the Evaluation phase of the fingerprint ACE-V process is explicitly linked to a subjective expert judgement of meeting a threshold of sufficiency for identification. NIFM association evidence does not incorporate a threshold. Rather, it makes a measure of the associative value of a correspondence. NIFM associations are explicitly not identifications and a better appreciation of their character results when one realizes that NIFMs are not a variation of fingerprint evidence (although both share the use of friction ridge detail as the basis for their associations).

NIFMs are a type of non-definitive evidence and, indeed, most types of evidence are non-definitive. NIFMs show a range of associative value, as do most types of evidence. Consider a parallel to circumstantial eyewitness evidence: having a potential contribution, but without any expectation of certainty, and with an acceptance of a range of credibility that must be carefully weighed within the context of the broader set of facts under consideration. NIFMs are within the broad class of non-definitive circumstantial evidence that has the potential to contribute to an accumulation of evidence, thereby contributing to an investigation or resulting in a convincing case. This perspective avoids a focus that the level of association provided by NIFMs is deficient (based on a comparison to traditional fingerprint identifications) and allows for the evaluation of potential contributions. Once viewed from within this perspective, NIFMs are found to be an exceptional class of non-definitive circumstantial evidence: they are already routinely and inexpensively collected, they can be objectively evaluated, they occur very frequently in cases, and they occur multiple times in each case. They are comparable to many eye witnesses in one case, each with a measurable credibility, testifying as to what was touched and by whom.

III. C. 2. The Materiality of Non-Identifiable Fingermark Evidence

Evidence is material if it relates to an element necessary for proving or disproving a case. There is no question of the materiality of NIFM evidence. Although NIFM evidence is conceptually distinct from fingerprint identification evidence, many aspects of materiality are similar. However, there are additional opportunities of materiality for NIFMs because of their greater abundance, smaller size and greater range of conditions under which they are made. The additional opportunities arise both from individual NIFMs and from their occurrence in combination with either identifiable fingerprints or other NIFMs. The following are examples of the materiality of NIFM evidence.

III. C. 2. a. Evidence Supporting or Refuting the Identity of a Person Touching a Surface

Most basically, NIFM evidence can provide support for either for a conclusion that a particular individual has touched a particular surface (making the mark), or for a conclusion that the mark was not made by the individual. The magnitude of this support depends on the measured associative value of the NIFM resulting from comparison of the NIFM with known (reference) fingerprints of the individual and comparison of the NIFM with a (large) database of fingerprints not from the individual. NIFMs provide a range of associative values, for or against the individual. Some are low, but most are very high. The average expected associative value, equivalent to a random occurrence of 1 in 380,000, is extraordinary within the context of non-definitive circumstantial evidence. Values of lower significance (e.g. 1 in 1000, which includes 86% of the NIFMs) are also clearly useful to provide evidential weight. However, very importantly, NIFMs occur in clusters at crime scenes. Multiple NIFMs can provide cumulative weights through their co-occurrence. The broader materiality of evidence supporting or refuting the identity of a person touching a surface is context dependent, based on the relationship of the surface to the crime and the uncertainties regarding when the touching could have occurred.

III. C. 2. b. Evidence Supporting the Identity of a Person Present at a Location

NIFM evidence can provide support for the presence at a location, when the NIFM is found on a surface attributable to a particular location (e.g. an unmovable surface or on an item otherwise proven to be at the location). Multiple NIFMs at one location can provide cumulative weight. Support against an individual being present at a location cannot result solely from disassociation of NIFMs with an individual, as persons do not necessarily leave prints when present at a location, nor necessarily when touching a surface.

The materiality of an association to a location (regardless of the strength of association) is context dependent. Where a defendant has no reasonable access to the location, the association could provide significant evidence. In cases with reasonable access, uncertainties regarding the timing of touching relative to the criminal events diminish materiality. In cases where a limited number of persons have access to an area, NIFMs can provide the means to support association with some of these persons, and support disassociation with others.

III. C. 2. c. Evidence Supporting Involvement of an Individual in an Activity

Apart from providing evidence of identity and presence at a location, the place and positioning of identifiable fingerprints or NIFMs can provide evidence of what an individual was doing. This is known as activity value.[40,41] Some examples are:

- Prints on the inner layers or tape of contraband packaging, indicating involvement in the wrapping process
- Prints on a handgun magazine, or on the ammunition within the magazine, indicating handgun possession and involvement with the loading process
- Prints on duct tape used to bind a victim, indicating involvement with an abduction
- Prints on a safe dial, strongbox key, or cash drawer, indicating involvement in a theft
- Prints on an automobile door handle, mirror, shift stick or key, indicating activities in a stolen vehicle
- Prints in blood indicating involvement with an assault or homicide
- Prints containing chemical contraband traces indicating involvement with, for example, drugs or explosives

Relative to identifiable fingerprints, the greater abundance of NIFMs provides more chances that activity can be shown. Furthermore, the smaller sizes of NIFMs means that they can be found on smaller surfaces, including areas that are clearly material, but where experience has shown that identifiable fingerprints are very rarely found; for example, on keys, automobile door handles, or ammunition. NIFMs are also more robust to contingencies such as pressure and movement when prints are left on a surface, or obliteration by subsequent handling or cleaning. That is, small portions of ridge detail, suitable for NIFM evidence, are more likely to survive such contingencies than would the more extensive areas of ridge detail in an identifiable fingerprint.

Multiple NIFMs at a crime scene, or NIFMs along with one or more identifiable fingerprints, provide additional opportunities to provide evidence of activity. Clusters of NIFMs can indicate greater than casual involvement. The scenarios shown in Figures 37 and 38 serve as examples. One identifiable fingerprint can establish the presence of an individual at a crime scene. The co-occurrence of a set of NIFMs, with measurable associative value to one individual, can show activity that is either highly indicative of criminal behavior or consistent with an innocent explanation.

III. C. 2. d. Evidence Supporting When an Individual was Present

It is not possible, from the nature finger marks themselves, to determine when they were made. The materiality of the fingerprints or NIFMs with respect to the time of a criminal action must therefore depend on combination with other related information or circumstances. For example, prints may be found on an item that was used in a crime, or that other evidence shows was touched or moved during criminal activity. Testimony of a burglary victim could establish when a surface was last cleaned or that an item was repositioning during a burglary. Touching of a counter during a robbery may be established by a victim's testimony or through security camera recordings. Other examples overlap those given above for activity value: prints may be made in blood, indicating presence when a person was bleeding, or prints may be on tape, indicating presence when the tape was applied.

That said, given the frequent presence of multiple NIFMs at a crime scene, there are increased chances of their occurrence under circumstances where they can provide evidence supporting when an individual was present.

III. C. 2. e. Improving or Diminishing the Credibility of Other Evidence

Like fingerprints, NIFMs can be used to improve or diminish the credibility of statements made by victims, witnesses or suspects. Multiple NIFMs at a crime scene provide additional opportunities to find evidence supporting or refuting statements regarding activities at crime scenes.

There are also opportunities for synergy with DNA evidence. Following documentation of their patterns, NIFMs may be sampled for DNA. The combination of a corresponding partial DNA profile and a corresponding NIFM, could result in a compelling identification as well as evidence that the DNA was transferred directly by touching.

III. C. 3. Summary

As noted above, NIFMs are within the broad class of non-definitive circumstantial evidence with the potential to contribute to an accumulation resulting in a convincing case. However, within this broad class they are rather exceptional:

1. They occur very often compared to other non-definitive types of circumstantial evidence.
2. They occur in a wide variety of case circumstances.
3. They often occur repeatedly, with many prints occurring in an individual case.
4. They have a measurable, and often very high, associative value.
5. They frequently have activity value.

These exceptional features lead to a frequent, high potential value within the context of a case.

There are also additional features relating to the practicality and benefit of NIFMs including:

- a very low cost to collect or process NIFMs
- a rapid process that can proceed with high throughput
- occurrence in high numbers of cases (many more than for identifiable fingerprints)
- contributions where results from identifiable prints and other evidence are ambiguous
- occurrence in locations of material significance, including locations where it is very unlikely to find identifiable fingerprints

III. D. Results: Assessment of Utility of NIFM Evidence in Different Stages of the Criminal Justice Process

We enlisted a broad, highly experienced group of professionals to help assess the utility of NIFM evidence at four stages in the criminal justice process and in a special category of difficult investigations:

- Aiding Criminal Investigations, Forensic Analysis and Investigative Decisions
- Aiding Prosecutorial Decisions Pre-Trial
- Evidence at Trial
- Post-Conviction
- Special Investigations
    - High Profile Critical Incidents
    - Cold Case Investigations
    - Serial Crimes
    - Gang Activity

Assessments were made of the potential contributions NIFMs could offer, as well as issues and possible improvements that might affect this potential. This portion of the results is focused on more general assessments of utility. Some issues that directly affect practicality are introduced. These issues, as well as those affecting implementation and risks, are considered in the section that follows this one.

III. D. 1. Aiding Criminal Investigations, Forensic Analysis and Investigative Decisions

III. D. 1. a. Providing More Thorough Evidence for Crime Scene Reconstructions

Multiple NIFMs can contribute to evidence allowing more thorough crime scene reconstructions. There is a greater opportunity for evidence providing activity value: showing what was actually done, in addition to the presence at the crime scene. The examples given in Figures 37 and 38 illustrate this contribution through evidence supporting the touching of multiple areas within the crime scene. These areas include material locations such as the key to a cashbox, the drawer from which the cashbox was taken, the trigger of a firearm, and the ammunition found within it. Additional examples are given in Section III. C. 2. c., including the presence on inner layers or tape of contraband packaging; prints on an automobile door handles, mirror, shift stick or key; prints in blood; and prints containing chemical contraband traces (such as drugs or explosives).

III. D. 1. b. Linkages among Cases

There is a reasonable potential of NIFM evidence to provide linkages among cases. This includes (1) inter-comparison of prints from different incidents, and (2) comparing NIFMs from different incidents with specific individuals.

Inter-comparison of prints from different incidents. Greater numbers of NIFMs, and the likelihood that NIFMs will be found at each case, allow for the possibility of inter-comparisons of NIFMs to link cases. This capability would be depend on the presence, in cases that are actually related, of NIFMs left by the same portions of the same fingers. If there are comparable activities for the cases, this is not unreasonable. Some examples are:

- Holding and positioning of paper while writing
- Folding paper bindles when packaging powered drugs.
- Loading of ammunition
- Opening an automobile door or repositioning a rear-view mirror
- Use of touchscreens on cell phones or other devices

The capability would also require development of a new method focused on finding and evaluating correspondences between pairs of NIFMs (as distinct from the capability used in the present research, which compares NIFMs to reference fingerprints). This is a reasonable possibility for further research, as is investigation of how often case linkages using such a capability would result.

Comparing NIFMs from different incidents with a specific individual. In circumstances where one case in a suspected series has been solved, and a responsible party identified, NIFM evidence provides an excellent means to determine if other cases are linked to the same individual. Major case prints of the identified responsible party would be directly compared to any recovered NIFM evidence. This task could be performed using existing AFIS methodology to find correspondences and the methods employed in this research (or an alternative) could be used to measure their associated strength. Linking of cases in this way is not dependent on NIFMs of the same portions of the same finger being present at the different crime scenes. Investigation of this capability is an area of reasonable follow-on research.

III. D. 1. c. Developing a Suspect

Developing a suspect using a single NFIM for a general AFIS database search. Existing AFIS capabilities can be used to develop suspects by searching a database of individuals for correspondence to an NIFM, followed by expert evaluations to test for a valid correspondence. The methods employed in this research (or an alternative) could be used to measure an associative value.

The feasibility of this approach would depend on a number of factors, including (1) the selectivity of the NIFM for AFIS searching, (2) the size of the database, and (3) the available effort for expert review of candidate resulting from the search.

1. Current practices employ AFIS searches only for identifiable fingerprints of higher quality. The higher quality and quantity of details in these fingerprints makes the prints highly selective, resulting in highly ranked AFIS scores for the individual who actually made the print. Fingerprint experts can then compare the known prints from the top ranked candidates to determine if there is a correspondence warranting a fingerprint identification. This process works efficiently because of the high selectivity of the higher quality identifiable fingerprints. If the individual who made the print is in the database, that individual comes up as one of the top candidates; usually the first, and almost always in the first ten. Experts can efficiently review a small set of top ranked candidates and either end the process with an identification or with a reasonable presumption that the individual who made the print is not in the database. When a

lower quality print, or one with fewer details, is used for searching, the print will have lower selectivity and the AFIS score for the individual who made the print would not necessarily be highly ranked. It might be necessary to search through an unreasonably large number of candidate individuals before encountering the person who actually made the print. Less selective prints, including NIFMs, will have AFIS scores where matching prints (those that ultimately pass expert evaluation of a correspondence) do not stand out prominently from those of non-matching prints.

2. The larger the database, and the lower the NIFM selectivity, the greater the difficulty discussed in the previous paragraph becomes. There will be more candidates that do not correspond which must be searched by experts to find any that do. However, it is expected that the most highly selective NIFMs would perform nearly as well as identifiable fingerprints. A threshold value of the ESLR of the NIFMs could be used, introducing a trade-off between the numbers of NIFMs that could be used for searching and the efficiency of the searching processes.

3. There is also the problem that, unlike for identifiable fingerprints, there is no clear endpoint to the database searching process. That is, identifications do not result from the finding of a correspondence, thereby completing the search. The result is an individual, or a set of individuals, who might have made the NIFM, along with estimates of the associative value of each of the correspondences. A potentially reasonable approach would be one that proceeds through the most highly ranked candidates, measures the associative values for any that pass expert evaluation for a correspondence, and stop the process when the computed associative value falls below a chosen threshold, say, 1 in 1000.

The effectiveness of developing suspects using NIFMs in a general AFIS database search using these (or other) approaches is a reasonable possibility for further research.

Developing a suspect using multiple NIFMs and the intersection of ranked AFIS score lists. The presence of multiple NIFMs from a crime scene provides a significant new opportunity for the generation of suspects using AFIS searching. This approach would not require the use of expert comparisons to screen candidates. Rather, it relies on automated computer screening and statistical analysis processes exploiting set intersections. Using the ranked candidate lists from multiple NIFMs, suspects would be developed based on their relatively higher ranking in the multiple lists. Using this approach the set of NIFMs provides a compounded selectivity, identifying suspects for evaluation. This evaluation could be followed by expert comparisons and measurement of associative values for the NIFMs, but it need not be. Suspects generated by this expert-independent AFIS process could be evaluated applying any other investigative technique or available case information. The effectiveness of multiple NIFMs to develop suspects through the intersection of their ranked AFIS score lists is an intriguing possibility for further research.

III. D. 1. d. Evaluating Suspects and Statements

Narrowing the pool of suspects in an investigation. The investigation process typically involves a list of individuals to be considered. Methods are useful that will narrow down the list or prioritize among members of the list. These methods do not need to be precise, definitive or admissible in court in order to be useful. If the information is enough to provide a reliable lead, it could be enough to solve the case. The analysis of NIFMs would be an easily available, efficient way to narrow down the suspect pool. They would provide useful information to the investigation, with an objective, measured value of their reliability for association. This would be extraordinary valuable for focusing the investigation and allocation of resources. Reliable leads that focus the investigation can result in additional evidence and end up solving the case. Finding a number of NIFMs with high associative value in a case therefore provides investigative options and recognizing that there is a ready means to screen suspects may provide the impetus to continue an investigation or assign higher priority to the case.

A case-specific or "limited known" AFIS search could be conducted using the NIFM prints. This approach uses a small, case-specific database, where the reference prints in the database are only those from a small number of individuals of interest in a single investigation. In contrast with the General AFIS Database Search (considered at the beginning of this section), the lower selectivity of NIFMs is unlikely to be problematic. The utility of this approach is a reasonable option for follow-on research.

Evaluating specific suspects. The presence of NIFMs in material locations provides an excellent and very useful means to evaluate specific suspects. When such prints are found in a case, there is a capability to objectively screen subjects as the investigation proceeds, helping to guide whether the investigation is on the right path and providing the impetus to keep going in a given direction or to choose another course of investigation. Importantly, the comparisons can result in supporting either that the suspect did, or did not make the NIFM. Finding NIFMs that were clearly made by the perpetrator, and that are very unlikely to be from suspect, provides support for exclusion of the suspect and redirection of investigative efforts.

Evaluating suspect and witness statements. Like fingerprints, NIFMs can be used to improve or diminish the credibility of statements made by victims, witnesses or suspects. Multiple NIFMs at a crime scene provide additional opportunities to find evidence supporting or refuting statements regarding activities at crime scenes. Statements such as the following can be evaluated with much greater chances of evidence supporting or refuting them.

> “I was at the burglary scene, but only touched the door (window), looked in briefly and did not touch anything inside.”
> “I was in the car, but wasn’t driving.”
> “I touched the outside of the cocaine bindles. I didn’t make them and never opened one.”
> “I did not throw away that handgun (knife, drugs, cell phone, keys, handbag).”
> “I saw the defendant touch the counter and open the cash register.”
> “The defendant ran across the street in front of me and touched the hood of my car.”
> “The box (containing the drugs) that you found in my backyard belongs to my ex-boyfriend.”

III. D. 1. e. Establishing Probable Cause

The accumulation of evidence sufficient to establish probable cause for a search is a significant milestone in an investigation, often leading to additional evidence. The same is true for establishing probable cause for arrest. As part of the broad class of non-definitive circumstantial evidence, NIFM evidence can contribute to these necessary accumulations of evidence. Further, as noted above, NIFMs are an exceptional class of non-definitive circumstantial evidence as they are already routinely and inexpensively collected, they can be objectively evaluated, they occur very frequently in cases, and they occur multiple times in each case.

III. D. 1. f. Aiding Forensic Crime Laboratory Analysis

NIFM methods and the resulting evidence can aid crime laboratory analysis by improving efficiency, increasing objectivity and providing more information from available evidence.

Improvements in analytical efficiency and throughput. Two specific areas where crime laboratory analyses can be improved by the analysis of NIFM evidence are (1) analysis of latent print suitability and (2) making better use of DNA evidence.

1. The efficiency and effectiveness of the initial evaluations of latent prints could be greatly improved by the use of NIFM analysis methods. Major cases typically result in the collection of large numbers of latent prints. Current practices, as part of the ACE-V examination process, involve expert examination and assessment of each print's suitability for comparison or identification. This requires not only a detailed analysis (data gathering), but also an expert decision (suitability). These are labor-intensive, required examinations in each case. The results of these examinations are important as they determine which prints go forward for possible use as evidence and which are set aside. However, these expert determinations are subjective decisions which are known to vary from examiner to examiner and it is difficult to standardize this process.

Using the methods employed in this research, incoming latent prints could be rapidly and inexpensively processed automatically, providing measurements of their expected associative value (ESLR). This has the potential to significantly improve analytical efficiency and throughput by providing an expert-independent method to select those prints with higher expected associative value. The automated screening process is quick, objective and provides a continuous measurement of value. This would replace a slow, subjective expert-dependent, yes-or-no decision process. Cases with higher quality prints can be recognized early in the process, without having committed expert resources. Difficult subjective assessments of suitability are avoided, and the presence of NIFMs of high associative value are recognized. Preliminary results showing the numbers of high value prints in a case, and the locations where they were found, can be used to advise investigators and for prioritization of casework assignments.

Application of ESLR measurements to the initial evaluations of latent prints is a reasonable area for follow-on research.

2. NIFM evidence can also contribute substantially to the efficiency of crime laboratory analyses by making better use of DNA evidence. DNA profiles are frequently obtained from the same surfaces on which fingerprints are left, or from fingerprint lifts themselves. Analyses for NIFM evidence and for DNA evidence can be coordinated and applied in ways that would increase efficiency and result in more robust information.

DNA analysis is commonly used as a means to associate individuals with a crime scene. However, much of the DNA at a crime scene is from the victim or other individuals known to be present and uninvolved with the crime. At major crime scenes many DNA swabs are collected and, in the effort to find DNA from the perpetrator, many or all of the swabs are analyzed. There are high associated costs, levels of effort and response times for this practice. NIFMs could be used to select which DNA specimens to analyze, resulting in better, less expensive use of DNA efforts. For example, NIFMs can provide evidence supporting which surfaces were touched by victims or witnesses (as in elimination prints) and which were touched by someone else. This can provide the motivation to select which DNA analyses to conduct.

The process could also be applied in reverse: the findings of DNA linked to an individual would provide the impetus to compare recovered NIFMs to that individual. This has the potential to prove that the DNA resulted directly from touching at the scene, diminishing the credibility of alternative explanations.

Evaluation of the contribution achievable from coordination of NIFM and DNA evidence analyses is a reasonable area for follow-on research.

Providing a means to report similarities that are less than definitive identifications. Current fingerprint examination and interpretation practices do not incorporate reporting of non-definitive associations. Examinations none-the-less sometimes reveal corresponding detail that is present, but insufficient in quality or quantity to justify the expert's opinion of an identification or exclusion. Informal or unofficial verbal reporting of such results sometimes occurs, but more typically the results are simply represented as inconclusive. (Thresholds for laboratory DNA reporting can act in the same way; partial profiles may match, but without reaching a reporting threshold results may simply be given as inconclusive.) Although investigators would find the non-definitive results useful, there is no means to officially receive these results. The use of NIFM evidence would provide an established means to report non-definitive findings, producing more available evidence and eliminating the lack of transparency. Instead of reporting a comparison as inconclusive, or that the fingerprint has no value for identification, information is provided that there is some ridge detail in correspondence, with a measured value.

Providing a means to develop expertise in NIFM interpretation. One of the consequences of setting NIFM marks aside, without attempting to make and interpret comparisons, is that professional expertise in their interpretation has not been developed. Conducting comparisons with these marks, and using computational aids to measure their associative value, will lead to the development and refinement of this professional expertise.

III. D. 1. g. Discussion of the Use of NIFMs for Criminal Investigations

It is clear that NIFM evidence would be highly valuable for investigative applications. Examples that have been given include linking cases, developing and evaluating suspects, testing the credibility of witnesses, establishing probable cause and aiding crime laboratory analysis.

Realization of most of these contributions would require implementation in a way that either embeds the capability within the investigating unit or ensures very rapid responses to the investigation unit's requests.

Taking full advantage of the potential of these contributions would require additional research. Research areas of interest noted in this section include:

- Development of methods for the inter-comparison of NIFMs from different cases and testing of the usefulness of NIFMs, by themselves, to link cases
- Evaluating the effectiveness of using NIFMs to link cases to specific individuals
- Evaluating the effectiveness of developing suspects using NIFMs in a general AFIS database search
- Design and testing of methods to develop suspects using multiple NIFMs and the intersection of ranked AFIS score lists
- Evaluating the utility of case-specific, “limited known” AFIS searches of NIFMs
- Application of ESLR measurements to initial latent print evaluations
- Evaluating the advantages of the coordination of NIFM and DNA evidence analyses

Taking full advantage of the potential of NIFM evidence would also require and modification of latent print collection practices to ensure that the smaller, more abundant NIFMs are recovered and retained during crime scene and laboratory fingerprint processing.

III. D. 2. Aiding Prosecutorial Decisions Pre-Trial

Prosecutorial decisions involve the weighing of many aspects of circumstantial evidence. The nature of the evidence upon which these decisions are made is cumulative. It is usually made up of many pieces, each non-definitive when standing alone, yet combining in weight to provide a basis for the prosecutor's decision.

NIFMs can contribute directly as an additional source of non-definitive circumstantial evidence – one which occurs very frequently, can be objectively evaluated, and occurs multiple times in each case. As such, NIFM evidence would be very helpful for district attorneys in their evaluation and presentation of cases. It could show greater or less involvement with criminal activity by the abundance or paucity of associated NIFMs, as well as implicating or rebutting the association of NIFMs found in key locations.

In many cases where fingerprint identifications are involved, the inability to show that the identified fingerprint was made during the crime is a significant weakness. This is true of touch DNA as well. Something about the fingerprint is needed that shows it has something to do with the crime. This issue was discussed, with examples, as one of the topics in Section III. C. 2. on the materiality of NIFM evidence. The presence of multiple NIFMs at a crime scene results in increased chances of their occurrence under circumstances where they can provide evidence supporting when an individual was present.

Combinations of NIFMs with other types of evidence also have the potential to remove ambiguities, resulting in compelling proof. An example is the co-occurrence of a partial DNA profile and an NIFM, both corresponding to an individual. Other examples are combinations of NIFMs with:

- Suspect or witness statements (see section III. D. 1. d.)
- Video recordings showing what items and/or locations were touched
- Recovered contraband or stolen property
- Co-occurrence with chemical residues of explosives, drugs or other trace materials

As a new approach that could be applied directly to evidence that has already been collected, NIFMs would be useful in the review of uncharged cases where there was a clear suspect, but borderline sufficiency to charge. In more important cases, where larger numbers of latent prints were collected, this source of new evidence would be well worth pursuing.

As noted in the previous section, the use of NIFM evidence would establish an avenue for reporting fingerprint comparisons that result in less than definitive associations. It is appropriate and important that any available evidence be provided to prosecutors for their decision-making. The lack of formal means to report non-definitive fingermark correspondences has the effect of either concealing part of the evidence (when it is not reported) or restricting its reporting to informal, less controlled and less transparent practices.

As with investigative applications aiding in investigations, in order for NIFM evidence to contribute to pre-trial decisions it must be available when these decisions need to be made. This means that there must be a rapid turn-around time for the analysis and reporting of NIFM evidence. Quick turn-around times can be problematic for current fingerprint examination practices: the very high thresholds of associative value, and nearly negligible rates of false association, require expert-intensive processes for conducting, verifying and reporting identifications. The realities of these expert-dependent processes and high caseloads mean that in many instances the findings from fingerprint examinations are not available much before trial. However, NIFM evidence is less expert-dependent, providing more favorable conditions for quick turn-around times. Firstly, in the examination process, the automated evaluations of ESLRs and measured associative values of NIFM comparisons are less expert-dependent than fingerprint comparisons and evaluations. Secondly, for quality assurance, the reliability of NIFM evidence is achieved by vetting or confirming a measurement method, rather than by the fingerprint verification process where a second expert-dependent examination is conducted.

Evaluation of the contribution of NIFM evidence in support of prosecutorial decisions pre-trial is a reasonable focus for follow-on research.

III. D. 3. Evidence at Trial

III. D. 3. a. General Contributions of NIFM Evidence at Trial

For admission as evidence at trial there are additional requirements. This includes those that are common to all types of evidence, as well as a set that are peculiar to NIFMs. Discussion of these aspects is included in Section III. E. Issues of Implementation, Risk and Perception.

Once developments have led to acceptance in the field, there is no reason that NIFMs cannot satisfy the rules of evidence and be introduced as part of a case in the role of non-definitive circumstantial evidence. Once vetted and accepted, NIFM evidence would be material and highly valuable for use at trial. Support for or against an individual making a NIFM is clearly evidence of interest to a jury, and informative to them. This type of evidence is often discussed in laboratories, but without an accepted means to interpret and report it, the information is lost. As noted in the previous section, a major contribution of NIFM methods to crime laboratories is providing a means of reporting these non-definitive associations. Once this capability is available, the introduction of NIFM evidence in court will necessarily follow.

It is important to re-emphasize that the evidential weight provided by a NIFM goes both ways. A given NIFM will provide evidence for or against its being made by a specific individual. This evidence can range from very weak to very substantial (but as noted above, we found a very substantial average value). The finding of NIFMs with high associative value in key locations, and the finding that these are very unlikely to be from the accused, can provide strong evidence of non-involvement. The opposite can provide strong evidence of culpability. Likewise, the finding of NIFMs in locations that are consistent with a defendant's prior statements can lend objective support for these statements – just as inconsistencies with prior statements can shed doubt upon them. It is clear, therefore, that NIFM evidence, by its nature, can support or refute arguments made by either the prosecution or the defense.

That being said, it is important to emphasize that objects and surfaces can be touched without the transfer of friction ridge patterns. This is true of NIFMs, as it is true of identifiable fingerprints. The absence of an NIFM associating a person with an item or surface does not demonstrate that that person did not touch the surface.

The structure of our legal system, and the distinctly different roles and responsibilities of prosecution and defense counsel, give rise to a set of issues that are shared with other forms of scientific evidence. These issues, including those relating to the burden of proof, access to the forensic laboratory, and discovery requirements are also considered as part of Section III. E.

Non-definitive associations, supported by measures of evidential weight are not novel. Analogies can be made to the use of blood type frequencies, before the development of DNA analysis methods, or to present situations when there are DNA mixtures. An association of "cannot be excluded along with 1 in every 500 individuals," is information. From a legal perspective all information is kept, filtered through rules of evidence and, subject to these rules, available as part of the case to the trier of fact. The trier of fact must put such numbers into context and give it evidential weight. However, the question of how numerical estimates of associative value ought to be presented to the trier of fact is not trivial. Related issues are currently debated and are the focus of active research. NIFM associations, as a class of evidence amenable to measurement of associative value, share in these broader issues, as further discussed in Section III. E.

As noted above, NIFM associations can range from very weak to very substantial. Suppose there is a comparatively weak association to an NIFM of "cannot be excluded along with 1 in every 500 individuals." A city with a population of 300,000 would be expected to have some 600 individuals with this degree of association. Is this level of an association useful? The answer depends, of course, on the case context. In cases with limited access, and where the NIFM was likely made by the person committing a criminal act, this information provides the trier of fact with significant evidence. For an area with more public access, and ambiguities regarding when the print was left, the useful information may be negligible, and assessed by the judge to be inadmissible.

III. D. 3. b. Specific Contributions of NIFM Evidence at Trial

NIFM evidence at trial has a number of specific potential contributions, many of which parallel the contributions to police investigations, forensic laboratory practices, and the aiding of prosecutorial decisions. The most general contribution is as a contributing piece of non-definitive evidence, whose value in supporting or refuting a case depends on how it fits with all of the other contributing pieces of evidence. As noted in Section III. C., NIFMs are an exceptional class of non-definitive circumstantial evidence, in part because they can be objectively evaluated and in part because they occur multiple times in each case. Specific potential contributions at trial include the following.

1. Associative or exclusionary value of NIFMs occurring in material circumstances. The smaller sizes and greater numbers of NIFMs provide additional chances that prints will be found in material locations. Examples given in Section III. C. include the finding of NIFM on the inner layers of tape used for the binding of contraband, prints on parts of weapons or ammunition, and prints made in blood.

2. More complete evaluations of activity and significance of friction ridge evidence. Multiple NIFMs at a crime scene, or NIFMs along with one or more identifiable fingerprints, provide additional opportunities to provide evidence of activity. Clusters of NIFMs can lead to better crime scene reconstructions and can indicate greater than casual involvement. The illustrations given in Figures 37 and 38 serve as one example. As another, it is not uncommon, when a single fingerprint identification links an accused to a crime scene, for a defense argument to be made that this single fingerprint identification to the defendant does not indicate involvement in the crime, since any of many other prints at the crime scene (identifiable or not) could be from the actual offender. NIFM evidence can address this argument. Testing of the NIFMs for correspondence to the defendant could result in multiple associations, with a range in associative values, effectively refuting the argument. Alternatively, the argument could be supported if the testing supports that, indeed, only one print corresponding to the defendant is present.

3. As means to help evaluate the credibility of statements and testimony. As noted earlier, NIFMs can be used to improve or diminish the credibility of statements made by victims, witnesses or suspects. Multiple NIFMs at a crime scene provide additional opportunities to find evidence supporting or refuting statements regarding activities at crime scenes.

4. Providing an official means to report latent print similarities that are less than definitive identifications. This aspect of NIFM evidence has been mentioned several times. Although it is outside of current fingerprint examination processes to report of NIFM associations and present an assessment of their associative value, evidence of similarities is admitted by some judges and presented by some examiners. Neither admitting an expert assessment of "consistent with" (which is sometimes done), nor exclusion based on vagaries of associative value combined with possible prejudice (which is sometimes done), do justice to the actual information that the NIFM evidence could provide.

III. D. 4. Post-Conviction Reviews

NIFMs provide a readily available, inexpensive means to review post-conviction cases. The collection of fingerprint evidence from crime scenes routinely includes the collection of NIFMs. The records are durable, compact, and almost always retained by crime laboratories or police departments as part of the permanent case record.

As noted earlier, current fingerprint evidence practices include an initial screening step (the Analysis portion of ACE-V) that results in a determination of whether a fingerprint is of value for identification. Prints falling below this threshold (NIFMs) are routinely set aside and not examined further. As such, they are an untapped source of information that is available for use as part of post-conviction reviews. Some examples of contributions of NIFMs for post-conviction are given below.

1. The capability to use NIFM evidence would provide an additional, inexpensive means for the initial review of post-conviction cases and could contribute substantially to their investigation.

2. Where cases are based substantially on a single identified fingerprint, NIFMs can be used for an additional assessment, reinforcing the findings or raising questions by the presence or absence of NIFM associations to the convicted individual.

3. Again, in cases where fingerprints were collected, but where no identifiable fingerprints were found, analysis of the NIFMs can provide support for the conviction, or provide new information on what occurred and who was involved. If NIFMs were recovered in material locations, their lack of association with the convicted individual may warrant further investigation, such as DNA analysis of the NIFM.

4. Comparison of NIFMs to alternative suspects, witnesses or otherwise involved individuals could provide significant information by placing others at the crime scene or providing support for or against the credibility of statements made during either the investigation or testimony at trial.

5. Importantly, there are also post-exoneration applications. The additional information provided by NIFM evidence can redirect investigative efforts to find the person or persons responsible for the crime.

Exploring the contribution of NIFM evidence to post conviction reviews is an important avenue for follow-on research.

III. D. 5. Special Investigations

Four types of special investigations have been identified where NIFM evidence is likely to have an exceptionally high impact.

III. D. 5. a. High Profile Critical Incidents

High profile critical incidents receive intense investigative and forensic laboratory effort. All possible sources of information receive attention and are pursued as quickly and aggressively as possible. NIFM evidence, as a readily available source of additional information would clearly be exploited. The manpower to pursue additional leads generated by NIFM evidence would be available.

III. D. 5. b. Cold Case Investigations

Cold case investigations usually begin within agencies with the creation of a Cold Case Unit and a review of all unsolved cases. The unit evaluates if there have been changes in 1) relationships or 2) available technology, that would enhance the ability to resolve the case. The use of NIFMs is a substantial change in available technology that should be considered and that could well have a high impact. Importantly, NIFM methods exploit evidence that has already been collected and can be part of an efficient, low cost evidentiary review.

As has been repeatedly noted, when laboratories work fingerprint cases they focus on fingerprints that have larger numbers of characteristics, setting aside the NIFMs. An agency can easily review files, pull cases, and look for the occurrence of NIFMs that were recovered from material locations or in contexts addressing key investigative issues. The occurrence of these NIFMs can serve as a means to select cases for allocation of additional investigative effort. Contributions to the investigation can be made in any of the ways discussed in Section III. D. 1.: linking cases, developing suspects, evaluating suspects and statements, establishing probable cause and improving crime scene reconstructions.

A major issue in successful cold case resolutions is evidence retention. As cold case investigation practices mature there are stronger retention practices. DNA has provided an important lesson: very simply, the revolutionary effect of DNA analysis cannot be applied where evidence has been not been retained. To enable the potential future application NIFM evaluations to evidence, it is important that latent fingerprint records be retained, even if they do not show latent prints that are considered identifiable or comparable by current practices.

III. D. 5. c. Serial Crimes

Serial crimes have a high impact on communities. They can have a very high profile, and the successful identification and prosecution of perpetrators can dramatically affect the reality and perception of public safety in a community. NIFMs can add a new capability to available methods to help identify perpetrators, but the more dramatic contribution is the enhanced capability to link cases. As noted above in Section III. D. 1. b., comparing NIFMs from different incidents with a specific individual is a directly applicable capability. Many NIFMs are routinely collected when crime scenes and items of evidence are processed for identifiable fingerprints. The known fingerprints of suspects or charged individuals can be easily checked for correspondence with NIFMs from multiple crimes. NIFMs are also easily shared across police jurisdictions, helping to link cases where a perpetrator may have changed areas of operation.

Associations of an individual with additional crimes has the effect of clearing more cases and helping to ensure that the responsible party is prosecuted appropriately. When associations are not found, this finding can help avoid inappropriate linking of cases, inappropriate charging of individuals, and inappropriate closing of cases. This will help to keep investigations open and identify multiple individuals who may be operating in the same geographical area and using similar methods.

III. D. 5. d. Gang Activity

The investigation and monitoring of gang activity is a difficult and high priority area of policing. The greater numbers of cases with NIFMs will provide a better means to associate activities with specific individuals in specific gangs, and provide evidence supporting relationships among members. The "limited known" AFIS database approach, discussed in Section III. D. 1. d., is likely to work well. NIFMs from suspect gang activities would be compared with a small, custom AFIS database containing the reference fingerprints of known and suspected gang members.

Overall, it is a reasonable area of follow-on research to explore the application of NIFM evidence to any of the above categories of special investigations: high profile critical incidents, cold case investigations, serial crimes or gang activity.

III. E. Results: Issues of Implementation, Risk and Perception

The utility of NIFM evidence assumes that suitable methods are implemented that address known risks and fairly meet the needs of the criminal justice community. This project included not only estimates of utility, but also a detailed consideration and assessment of both the developmental needs and risks of implementation. This assessment includes discussion of concerns expressed by the broad range of individuals who participated in the study. The research results are presented in the following groups.

1. This is a New Method, Not Fully Developed. A set of issues and concerns that stem from the current stage of development of NIFM evidence, as used in this project.

2. The Reasonableness of the Concept and Approach. Responses to the overall reasonableness of the concept and approach, assuming other requirements can be met.

3. General Forensic Science Issues Shared by NIFM Evidence. A set of issues, concerns and risks that are in common with the general practice of forensic science.

4. Issues Specific to NIFM Evidence. A set of significant issues for the effective implementation of NIFM evidence.

5. Role-Driven Perspectives and Issues with Factual Information. A set of concerns closely linked to the adversarial roles of opposing counsel in our criminal justice process, or to a generalized risk of decision-making based on facts or forensic analytical findings.

III. E. 1. This is a New Method, Not Yet Fully Developed

The present research was undertaken to assess the occurrence and utility of NIFMs in order to better understand the potential and provide a foundation for consideration of further research and applications. The method that was used was suitable for the research objectives, but is by no means necessarily the best or fully developed method for casework applications. Specific aspects that need development for exploitation of NIFMs include:

- Measurement methods that have been vetted and that are responsive to issues regarding alternative approaches that are currently being debated in the forensic community at large
- Establishment of scientific validity and underlying support
- Clear definitions of limitations

There is also a need, as in any new method, of education for participants, including attorneys and judges. The education and guidance in the use of new technologies is always important, and more so as forensic science operates under greater scrutiny and with more oversight in the post-NAS report era. Given the exclusive historical use of fingerprints as an accepted method for conclusive identification, there will be a major issue in the education of lawyers and judges regarding what NIFM evidence can and cannot do and how it should be presented. (The topics under this heading are also considered below as part of Section III. E. 4. Issues Specific to NIFM Evidence.)

III. E. 2. The Reasonableness of the Concept and Approach

The probabilistic approach to NIFM evidence is reasonable. We encountered no arguments or indications that the methods taken in this research were conceptually flawed. We received no negative feedback regarding this approach and much positive feedback that it made sense to make use of NIFMs, assuming other requirements could be met.

However, not all agree, in principle, to the usefulness of this type of evidence. These concerns are discussed in the other topic areas within this section and are related to the acceptance of real or perceived risks, many of which are in common with forensic science generally, or with issues associated with the determination and presentation of numerical estimates of evidential weight.

Feedback included assessments from latent fingerprint examiners that the technical requirements of the new approach are not that far off from what is currently being done. Laboratories have been preparing for probabilistic assessments of fingerprints, supplementing or replacing identification decisions. NIFM evidence is a natural extension of this process in the evolution of the field. Furthermore, it is a more complete and open description of the evidence.

Analogies were made between NIFM evidence and the use of low quality DNA evidence, including distinctions between a) a low quality signal, and b) a low amount of a high quality signal. For fingerprints, a low quality signal would be a very blurry fingermark, with indistinct details (and not part of this research), whereas NIFMs would be lower amounts of a high quality signal. Both types of fingermarks (mere smudges and NIFMs) are currently being used to mine for DNA. It is very feasible to include an initial step where the ridge detail is documented, before collecting the fingermark for its potential DNA signal. While there are problems with the effect of some fingerprint development methods (e.g. ninhydrin), most leave the DNA signal intact.

Further comparisons to DNA evidence were the absence (for NIFMs) of up-front costs (to reveal the presence of DNA evidence) and the ready availability of fingerprint databases and searching methods to nearly all investigative agencies and forensic laboratories (as opposed to the availability of DNA databases to only some).

From a legal perspective, once it is appropriately developed, NIFM evidence would clearly be useful, of interest to a jury, and informative to them. It could make a legitimate difference in the outcome of the case. As such there would be no legal basis to hold it back, apart from meeting general requirements for admissibility.

III. E. 3. General Forensic Science Issues Shared by NIFM Evidence

There are important and meaningful perspectives that are part of the appropriate and constructive debate on the uses of forensic science, but that are not specific to the use of NIFM evidence. NIFM evidence must be able to address these concerns, but the issues for NIFMs are not distinct from those encountered in other types of evidence that are already in common use. For example:

- There are questions of how a method is implemented in the laboratory, what checks are in place for quality assurance, and what thresholds there are for reporting

- There is the issue of how probabilistic measurements of the weight of associative evidence should be presented
- There are possible admissibility issues applicable in some cases, beyond scientific validity
- There is the potential for misuse of non-definitive associations by law-enforcement or prosecutors during investigations, arrests, and charging
- There is a more generalized aversion to evidence that, when viewed in isolation, has non-compelling levels of associative value

Some aspects of these issues, as applied to NIFM evidence, are discussed in the remaining portions of this section.

III. E. 4. Issues Specific to NIFM Evidence

Significant issues relating to the exploitation of NIFM evidence are discussed in the following groups.

a. There must be a well-developed measurement method with well-documented scientific support
b. There is a need for concurrent development of methods showing NIFM support for and against associations with a given individual
c. Contributions of NIFM evidence to investigations requires timely, coordinated analyses
d. Resources must be allocated to NIFM evidence analysis commensurate with the utility of the additional information provided
e. It is essential that education regarding the nature of NIFM evidence be provided to all participants
f. Implementation must be planned in a way that addresses the above needs as well as other issues of general forensic science concern

III. E. 4. a. There must be a well-developed measurement method with well-documented scientific support

As noted above, the present research was undertaken to assess the occurrence and utility of NIFMs in order to better understand the potential and provide a foundation for consideration of further research and applications. The method that was used was suitable for the research objectives, but is by no means necessarily the best or fully developed for casework applications. Whatever measurement methods are ultimately used must be vetted and responsive to the current debate regarding the merits of alternative approaches to the statistical analyses of fingerprints.

Any measurement method used for casework must have established scientific validity and underlying support, with clear definition of the limitations. Defining and vetting of the measurement method is the most central of the developmental needs to enable NIFM evidence. The validity of the quantification method must be established on theoretical grounds and with empirical testing using ground truth data sets. The robustness of the measurements must be determined. If the methods utilize a database of known fingerprints for their calculations (as in the present research), then an important part of the vetting is testing the effect of what database is used.

Measurement methods will have three distinct applications. The first, as applied in this project, is to measure the expected associative value of a fingermark, standing alone, in the absence of a putative source. This application would be used in casework for the recognition of which fingermarks could result in useful associative (or exclusionary) evidence in a given case. A useful measurement method for this application would result in (1) the efficient and effective grading of fingermarks, allowing rapid screening for potential value, and (2) meaningful representation of the potential values of associative or exclusionary evidence that could arise from each mark. Depending on possible trade-offs in performance and efficiency, this method might rely solely on auto-encoded minutiae, as applied in this project, or it might incorporate expert annotations of minutiae. Given that the purpose of this application is the screening and grading of fingermarks, rather than measuring the value of a comparison to an individual, it is reasonable to investigate if the acceptable levels of measurement performance for this application can be lower than those for the other applications.

The second application is the measurement of associative value of an actual comparison between an NIFM and a corresponding reference fingerprint from a known individual. This process would (1) rely on paired features between a fingermark and reference fingerprint and (2) may well incorporate expert annotation or verification of features (rather than relying solely on auto-encoding of minutiae). These results will produce measures of actual evidential weight, will initially be subject to evidentiary hearings, and will likely take a period of time to gain wide support.

The third application is the measurement of exclusionary value: support that the fingermark was not made by a particular individual. This process would (1) likely incorporate expert annotation or verification of features (rather than relying solely on auto-encoding of minutiae), and (2) likely involve comparisons to complete reference finger and palm prints of the particular individual. These results will also produce measures of actual evidential weight, will initially be subject to evidentiary hearings, and will likely take a period of time to gain wide support.

The range of utility of NIFM evidence presented in Section III. D. includes not only the potential use of NIFM evidence at trial, but its use during criminal investigations, for assisting with pre-trial decisions, and for post-conviction applications. For use at trial, including measures of actual evidential support for association or exclusion of NIFMs, it is expected and appropriate that the foundations for any measurement method will be questioned in evidentiary hearings. The strongest validation of the methods and level of performance will be needed for this direct, evidentiary use.

The uses for NIFM evidence at other stages in the criminal justice process will not encounter as high a level of scrutiny, nor will they require as high a degree of vetting in order to be useful and fit-for-purpose. Importantly, their suitability for a given purpose should be no less rigorously examined with respect to scientific reliability, but the acceptable levels of measurement performance may well be lower, and demonstrably persuasive arguments in evidentiary hearings will not be required.

III. E. 4. b. There is a need for concurrent development of methods showing NIFM support for and against associations with a given individual

The third application mentioned in the previous section was is the measurement of exclusionary value: support that the fingermark was not made by a particular individual. The reality is that the same methods that measure the associative value of a comparison also measure the exclusionary value, based on the lack of fit for the best possible correspondence with the fingerprints of a known individual. The modeling requirements for concurrent development are not demanding, but for meaningful results the procedure may well, as noted above, require comparisons to complete reference finger and palm prints of the particular individual.

Concurrent development of methods showing NIFM support for and against associations is necessary to bring the capability to its full potential. This will maximize the information available from NIFMs in any given case and will bring important balance to the methodology.

III. E. 4. c. Contributions of NIFM evidence to investigations requires timely, coordinated analyses

NIFM evidence can make extraordinary contributions to criminal investigations. However, these contributions are dependent on timely analyses, coordinated with the needs of these investigations. This is part of a greater issue in forensic science in that much forensic evidence, including fingerprint evidence, is underutilized because of high case backlogs, leaving most investigative and charging decisions to be made independently of these results.[42] Recognizing the strong potential contribution of NIFM evidence to investigations, and the relatively low demands on expert resources, it is important that investigators either have this capability imbedded directly in their units, or have it available as part of a real-time, interactive service from forensic laboratories. Concerns regarding contextual bias and insulation of laboratory testing from investigative details should not be controlling. It is essential that results be available in real-time and that contextual details are actually utilized as part of the interpretations. Should issues of possible contextual bias need additional controls, a separate re-analysis of the any evidence to be used at trial could be employed (with very little additional effort).

This challenge affects all forms of evidence and is more problematic for some types than others. Because NIFM evidence can be efficiently automated this challenge is less problematic and more easily addressed than for most forms of evidence.

III. E. 4. d. Resources must be allocated to NIFM evidence analysis commensurate with the utility of the additional information provided

It is unrealistic to expect that NIFM evidence analyses could be added to an existing fingerprint analysis unit without the allocation of additional resources. There would be more effort required. In general, the offering of any forensic science activity involves consideration of tradeoffs between costs and benefits. NIFMs have a strong potential to provide significant additional, useful, information. It this proves to be the case, the allocation of additional resources would clearly be justified. As much of the work is likely to be computerized, requiring minimal commitment of expert resources, the benefits provided, relative to the additional costs, are expected to be very high.

III. E. 4. e. It is essential that education regarding the nature of NIFM evidence be provided to all participants

Education of participants, including investigators, forensic scientists, attorneys and judges, is important when any new forensic science capability is brought on-line. However, this education will be particularly important for NIFM evidence because of the ubiquitous, closely related practice of fingerprint identification. The general public, and all criminal justice participants, have a pre-existing experience with fingerprints which involves their appearance as evidence only when experts make decisions regarding either identifications or exclusions. In Section III. C. we began our discussion of the character of NIFM evidence by emphasizing the fundamental distinction between NIFM association evidence and fingerprint identification. There will be a major issue in the education of lawyers and judges regarding what NIFM evidence can and cannot do and how it should be presented. Necessarily included as part of this task is the difficult, more general forensic science issue of how probabilistic measurements of the weight of associative evidence should be presented in court.

It should not be assumed that forensic scientists or prosecutors will be equipped to present NIFM evidence, nor that defense attorneys will be equipped to properly question it, nor that judges will be equipped to act as effective gatekeepers for its admissibility Rather, education regarding the nature of NIFM evidence should be provided to ensure that this is the case.

III. E. 5. f. Implementation must be planned in a way that addresses the above needs as well as other issues of general forensic science concern

Utilization of NIFM evidence would be a major new form of physical evidence. Its introduction should be planned so as to ensure that the measurement methods have solid scientific support, that these methods include support both for and against associations to specific individuals, that investigative contributions are ensured, that sufficient resources are allocated, and that proper education is provided to participants.

For many traditional forensic science practices, additional scrutiny since the NAS report[43] has led to actual or proposed changes in how forensic analyses are conducted or reported. As a new form of evidence emerging in this post-NAS environment, implementation should be carefully planned so that it addresses concerns such as those resulting from the reviews of other forensic methodologies. Implementation should include quality assurance checks that ensure that the methods are not applied overly aggressively. These should include explicit requirements for reporting and testimony, such as minimal thresholds for reporting of associations, required reporting of exculpatory findings, and well-defined guidelines for presenting probabilistic findings in court. Procedures might also include re-analysis of NIFM evidence in a way that is free of contextual bias if it is to be used in court.

The integration with current crime scene investigation and laboratory practices should also be planned. For example, latent print processing and collection should include the collection of

NIFMs from any material locations that might previously have been omitted because of the unlikely occurrence of identifiable fingerprints. Another example is including photographic documentation of any detail within NIFMs before swabbing for the recovery of DNA.

III. E. 5. Role-Driven Perspectives and Issues with Factual Information

Some specific issues and differences in the view of the utility of NIFM evidence arose from different roles in the justice process. A sub-set of prosecutors, as well as a sub-set of defense attorneys voiced such concerns. Some prosecutors were concerned with maintaining a strong perception of the strength of fingerprint evidence – one that might be diminished, or made more problematic, with the introduction of non-definitive NIFM evidence. Furthermore, the additional tests and results on NIFMs could result in more vulnerable cases and additional Brady obligations. What if many prints at the crime scene did not show association with the accused?

Similarly, some defense attorneys took general views that the non-definitive NIFM evidence should not be admissible at all, that it would be easily misunderstood, that there would be higher risks of misuse, or that more tests and data would make it worse for defendants, not better. What if many prints at the crime scene showed association with the defendant?

A small sub-set of forensic scientists also voiced concerns that non-definitive findings would be problematic, that results of any forensic science method should fit into well-defined categories, and that numerical estimates of the weight of evidence result in confusion for end-users, with increased possibilities of misinterpretation.

We share the views that NIFM evidence, or other presentations of probabilistic measurements of evidential weight, could be easily misunderstood. We also share the view that there is the potential for misuse of non-definitive associations by law-enforcement or prosecutors during investigations, arrests, and charging. There is also the potential for distortion of non-definitive associations by defense attorneys during argument or cross-examination. However, these issues are shared by many other types of evidence. They are not peculiar to NIFMs.

We take the view that non-definitive associative evidence is material and can be informative, that there is currently a high level of community awareness of possible misuses of forensic evidence, that mechanisms to address these concerns are in place, and that given these, perceptions of unfair advantage to either the prosecution or the defense are unwarranted. We also take the view that it is indefensible to consciously seek less information regarding material facts in a case as a response to the possibilities that reliable information might be misused, that it might be awkward, or that it might present a strategic disadvantage.

For fingerprint evidence in particular, our view is that quantitative methods for the assessment of associative value, once properly vetted, will lead to increased objectivity and scientific reliability for both fingerprint identifications and NIFM evidence. The evidence arising in specific cases may indeed increase difficulties for either the prosecution or the defense, but this will be an appropriate consequence of more reliable scientific information applicable to individual cases.

IV. Project Summary

The goal of this project was to make a reasonable measurement of the occurrence and usefulness of latent print correspondences that are insufficient for identification, providing a factual basis to set the priority for development and validation of methods to exploit their use.

Non-identifiable fingermarks (NIFMs) were found to commonly occur. In cases where marks of value for identification occur, there are almost always NIFMs and in greater abundance. While it was not tested, it is likely that NIFMs also occur in cases where fingermarks are not collected for one reason or another (for example, on unfired rounds of ammunition, where past experience indicates that identifiable fingermarks are not to be expected). It is also clear that objective, quantitative measures of associative value, such as the ESLR, can be applied to NIFMs and that there is a strong potential for a high degree of association. (The mean value in this work was equivalent to a random occurrence of 1 in 380,000).

NIFM evidence was found to be distinctly different from fingerprint identification evidence. NIFM evidence shows a range of associative value and is part of the broad class of non-definitive circumstantial evidence that has the potential to contribute to an accumulation of evidence, resulting in a convincing case. Within this class of evidence, NIFMs are exceptional. They are already routinely and inexpensively collected, they can be objectively evaluated, they occur very frequently in cases, and they typically occur multiple times in each case. They are comparable to many eyewitnesses in one case, each with a measurable credibility, testifying as to what was touched and by whom.

NIFM evidence is material. It can support or refute the identity of a person touching a surface, provide evidence supporting the identity of a person present at a location, and provide evidence supporting involvement of an individual in an activity. It can combine with other facts in a case to show when a surface was touched, or to improve or diminish the credibility of other evidence.

Research has revealed a wide range of contributions at different levels in the criminal justice process, including the aiding of criminal investigations, forensic analysis and investigative decisions; aiding prosecutorial decisions pre-trial; providing evidence at trial; in post-conviction reviews and in special investigations such as high profile critical incidents, cold case investigations, serial crimes and gang activity. Overall, there is a high potential impact for a highly occurring type of physical evidence, which will require minimal additional effort to implement.

Some areas of application are suitable for immediate use. Other areas require further development or research in the methods and still others require developments in forensic science as a whole.

Significant issues for the implementation of NIFM evidence are:

1. There must be a well-developed measurement method with well-documented scientific support
2. There is a need for concurrent development of methods showing NIFM support for and against associations with a given individual
3. Contributions of NIFM evidence to investigations requires timely, coordinated analyses

4. Resources must be allocated to NIFM evidence analysis commensurate with the utility of the additional information provided
5. It is essential that education regarding the nature of NIFM evidence be provided to all participants in various roles within the criminal justice process.
6. Implementation must be planned in a way that addresses the above needs as well as other issues of general forensic science concern

Other issues of general forensic science concern include:

- how a method is implemented in the laboratory, what checks are in place for quality assurance, and what thresholds there are for reporting
- how probabilistic measurements of the weight of associative evidence should be presented
- potential misuse of non-definitive associations by law-enforcement or prosecutors during investigations, arrests, and charging

Reasonable areas for follow-on research have been identified, including

- Development of methods for the inter-comparison of NIFMs from different cases and testing of the usefulness of NIFMs, by themselves, to link cases
- Evaluating the effectiveness of using NIFMs to link cases to specific individuals
- Evaluating the effectiveness of developing suspects using NIFMs in a general AFIS database search
- Design and testing of methods to develop suspects using multiple NIFMs and the intersection of ranked AFIS score lists
- Evaluating the utility of case-specific, “limited known” AFIS searches of NIFMs
- Application of ESLR measurements to initial latent print evaluations
- Evaluating the advantages of the coordination of NIFM and DNA evidence analyses
- Evaluation of the contribution of NIFM evidence in support of prosecutorial decisions pre-trial
- Exploring the contribution of NIFM evidence to post conviction reviews
- Exploring the application of NIFM evidence to areas of special investigations including high profile critical incidents, cold case investigations, serial crimes and gang activity

Overall, the priority next steps in moving toward in the implementation of NIFM evidence are (1) exploring the actual value of NIFM associations in investigations, (2) further development of measurement methods for NIFM associations, (3) development of processes for searching NIFMs among small groups of individuals, and (4) exploring the usefulness of NIFM evidence as part of post-conviction reviews.

Anticipating the future application NIFM evaluations to evidence it is important that latent fingerprint records be retained, even if they do not show latent prints that are considered identifiable or comparable by current practices. Furthermore, latent fingerprint collection practices should be revisited to ensure that the smaller, more abundant NIFMs are recovered and retained during crime scene and laboratory fingerprint processing, especially when they are present in material locations.

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VI. Dissemination of Research Findings

A. Research Publications

At the time of this report one research publication has been published and another is in preparation.

Stoney, DA, De Donno, M, Champod, C, Wertheim, PA and Stoney, PL: Occurrence and associative value of non-identifiable fingermarks, *Forensic Science International*, Volume 309, April, 2020. https://doi.org/10.1016/j.forsciint.2020.110219

In preparation:
Stoney, DA and Stoney, PL: Potential contributions of non-identifiable fingermark evidence and issues affecting their utility.

B. Published Abstracts

Stoney, D.A. Occurrence and Utility of Latent Print Correspondences That Are Insufficient for Identification (abstract), in 2018 Impression, Pattern and Trace Evidence Symposium (Conference Proceedings), Jones, N.S. (Ed.), RTI Press, pp. 64-65, 2018.

De Donno, M, Champod, C, Stoney, DA, and Stoney, P, Assessing the Expected Weight of Evidence for a Latent Print (Fingermark) that is Insufficient for Identification and Without Reference to a Putative Source, (abstract), Proceedings of the American Academy of Forensic Sciences, Vol. 25, p. 300, 2019.

Stoney, DA, De Donno, M, Champod, C, and Stoney, PL, Associative Value of Latent Print Correspondences that are Insufficient for Identification, (abstract), Proceedings of the American Academy of Forensic Sciences, Vol. 25, p. 301, 2019.

C. Research Presentations

De Donno, M, Champod, C, Stoney, D, and Stoney, P, Assessing the Expected Associative Value of Fingermarks Deemed of “No Value” using a Score-based Likelihood Ratio,” (Christophe Champod, presenting), European Network of Forensic Science Institutes (ENFSI) Fingerprint Working Group Meeting, Pointoise, France, September 13, 2017.

De Donno, M, Champod, C, Stoney, D, and Stoney, P, Assessing the Expected Associative Value of Fingermarks Deemed of “No Value” using a Score-based Likelihood Ratio,” (Christophe Champod, presenting), International Fingerprint Research Group (IFRG) Meeting, Beijing, China, October 18, 2017.

Stoney, D, Stoney, P, Champod, C and De Donno, M , Occurrence and Utility of Latent Print Correspondences that are Insufficient for Identification, NIJ Impression, Pattern and Trace Evidence Symposium, Arlington, VA, January 25, 2018.

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De Donno, M, Champod, C, Stoney, DA, and Stoney, P, "Assessing the Expected Weight of Evidence for a Latent Print (Fingermark) that is Insufficient for Identification and Without Reference to a Putative Source," American Academy of Forensic Sciences 71st Annual Meeting, Baltimore, MD, February 21, 2019.

Stoney, DA, De Donno, M, Champod, C, and Stoney, PL, "Associative Value of Latent Print Correspondences that are Insufficient for Identification," American Academy of Forensic Sciences 71st Annual Meeting, Baltimore, MD, February 21, 2019.

Stoney, D.A., De Donno, M., Champod, C., and Stoney, P.L., "Occurrence and Utility of Fingermarks that are Not Identifiable Fingerprints," California Association of Crime Laboratory Directors Conference, Oakland, CA, May 14th, 2019.

Stoney, D.A., "Occurrence and Utility of Fingermarks that are Not Identifiable Fingerprints," California Association of Criminalists Spring Seminar, Oakland, CA, May 16th, 2019.

Stoney, D.A., De Donno, M., Champod, C., and Stoney, P.L., "Occurrence and Utility of Fingermarks that are Not Identifiable Fingerprints," 2019 International Association for Identification Educational Conference, Reno, Nevada August 15, 2019.