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The Decomposition of Return on Investment for Forensic Laboratories

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Abstract *For forensic laboratories, a detailed understanding of return on investment (ROI) is necessary for routine assessment, consideration of new legislative alternatives, and cost-benefit analysis for decision making. Converting performance data to ratio measures provides useful comparisons between an individual laboratory and the standards for excellence for the industry; these measures also permit an evaluation across time. Unfortunately, these same ROI measures are subject to abuse when overemphasis on a single measure leads to unintended consequences. In this paper, the ROI measure is broken down into various parts that can be tracked on a regular basis to reveal how a laboratory achieves its results. The tradeoffs between return and risk, efficiency, analytical process, and market conditions are outlined. The end product is a series of easily monitored metrics that a laboratory director may examine on a regular basis for continuous improvement.*

Keywords Economics, finance, forensic labs, management, strategic planning

Introduction

Leaders across all types of organizations seek means for continuous improvement in the performance of their organizations. When it comes to practicing methods that efficiently tie daily performance to success of the organization, managers of forensic laboratories face similar problems to those faced by hospital administrators or corporate chief executive officers. Constant feedback is necessary for timely action. The determination of the metrics most appropriate for each industry is the challenge.

To determine which metrics will be most valuable, it is critical to start with an examination of the mission, vision, and values of an organization. What are the goals of an organization and what does it hold to be most valuable? Good metrics will point toward success along the way, toward important goals, and toward change in policy or practice to better reach organizational goals.

Unfortunately, the service industry of forensic laboratories does not follow a standard practice with respect to the collection and publication of data that might assist in the management of resources. Recently, two studies offered some hope for the standardization of language and the development of tools to meet the goals of forensic laboratories. The first study, QUADRUPOL—Development of a Benchmarking Model for Forensic Laboratories (2003), offered a standardized definition set for measurement of the inputs and non-financial outcomes of forensic laboratories in Europe. The second study, FORESIGHT NIJ—Measure, Preserve, Improve, adopted the foundation created in the QUADRUPOL study and expanded it to include connections between casework, operational expenditures, and personnel detail for laboratories across North America.

In this paper, the language of these studies is preserved as various metrics are considered. The next section examines a simple analytical technique that breaks down return on investment goals into component parts of tractable metrics for comparison for a laboratory over time or for comparison across the industry.

Connecting Goals to the Optimization Problem

Consider the performance of the forensic laboratory attempting to successfully process as many cases as possible given its level of funding. The ratio of cases processed to total expenditures provides one possible description of the return on investment (ROI) for a forensic laboratory,

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and it is a measure that is comparable to other laboratories. Additionally, the inverse of the measure represents a much-requested measure: average cost per case. In the presentation of various metrics for forensic laboratories, Speaker (2009) cautions about the potential abuse that can occur when attention is limited to a single measure. Fortunately, authors in several disciplines (see Burns, Sale, & Stephan, 2008; Pares, 1980; and Soliman, 2008, for some examples) have presented the mechanisms by which that caution can be mitigated.

To see how a laboratory might be able to extract valuable information from some common metrics, begin with the ROI measure above. By measuring the cases processed to the total laboratory expenditures, we construct a metric for ROI that can be compared across laboratories and across time.

$$\frac{\text{CASE}}{\text{TOTEXP}} = \frac{\text{AreaCasesProcessed}}{\text{TotalExpenditures}} \tag{1}$$

where the variables above follow the definitions from the QUADRUPOL/FORESIGHT studies, namely:

- An area case refers to a request for examination in one forensic investigation area.
- Total expenditures include the sum of the direct expenses (personnel, operating, and investment) and any administrative or other overhead expenses.

(Note that a full listing of the common definitions adopted by the European Quadrupol and U.S. Foresight studies is compiled in Appendix A.)

Once a laboratory begins to track this ROI measure, there are several ways in which forensic laboratory managers might increase this ratio over time. Strategies to increase efficiency or to modify processes may have a very positive effect on performance; but it is also possible to improve this ROI measure by undertaking practices that might not be so desirable, particularly via increases in risk taking. A decomposition of the ROI measure improves the information content of the return ratio by breaking it down into a variety of components to express managerial decisions and other conditions that contribute to the return. That is, can we devise a usable relationship between ROI and the various components that influence the rate of return?

$$\begin{aligned} ROI = {} & f(\text{efficiency, quality/risk management,} \\ & \text{analytical process, market conditions}) \end{aligned} \tag{2}$$

Examples of alternative ratios in each of these categories are described by Speaker (2009). These include amongst others:

- Efficiency measures such as cases processed per full-time equivalent employee;
- Quality/risk management measures such as tests performed per area case;
- Analytical process measures such as personnel expenditures/total expenditures; and
- Market condition measures such as the average compensation per employee.

The key for such a breakdown was developed in 1919 by DuPont executive F. Donaldson Brown as he attempted to analyze another company in which Dupont had made a substantial investment. Brown realized that higher ROI resulting from improvements in efficiency were highly desirable, while higher ROI that was merely accompanied by higher risk was to be avoided. The technique, a DuPont expansion, calls for the transformation of the ROI measure into component parts via an expansion from multiplication by the number 1 in various forms.

To demonstrate, first consider some additional notation and the definitions from the QUADRUPOL/FORESIGHT nomenclature. The present ROI expansion will occur when we multiply the ROI measure by the following forms of the number 1.

$$1 = \frac{\text{LEXP}}{\text{LEXP}} = \frac{\text{FTE}}{\text{FTE}} = \frac{\text{TEST}}{\text{TEST}}$$

where the notation and QUADRUPOL/FORESIGHT definitions are:

- LEXP refers to personnel (labor) expenditures and includes the sum of direct salaries, social expenses (employer contribution to FICA, Medicare, workers' comp, and unemployment comp), retirement (employer only contribution toward pensions, 401k plans, etc.), personnel development and training (internal or external delivery, including travel), and occupational health service expenses (employer contribution only).
- FTE or full-time equivalent employee is the work input of a full-time employee working for one full year.
- TEST represents tests completed. A test is an analytical process including, but not limited to, visual examination, instrumental analysis, presumptive evaluations, enhancement techniques, extractions, quantization, microscopic techniques, and comparative examinations. This does not include technical or administrative reviews.

Consider the insertion of these alternative expressions of the number 1 as multiplicative terms in the relationship defined in (1).

$$\frac{CASE}{TOTEXP} = \frac{CASE}{TOTEXP} \times \frac{LEXP}{LEXP} \times \frac{FTE}{FTE} \times \frac{TEST}{TEST} \tag{3}$$

By rearranging the order of the terms in the numerator and denominator, we unveil other metrics that have meaning with respect to the arguments in the functional relationship described in expression (3).

$$\frac{CASE}{TOTEXP} = \frac{CASE}{TEST} \times \frac{LEXP}{TOTEXP} \times \frac{FTE}{LEXP} \times \frac{TEST}{FTE} \tag{4}$$

$$\frac{CASE}{TOTEXP} = \frac{\frac{TEST}{FTE} \times \frac{LEXP}{TOTEXP}}{\frac{LEXP}{FTE} \times \frac{TEST}{CASE}} \tag{5}$$

Or, using the ratio definitions provided in Speaker (2009), this becomes:

$$ROI = \frac{LaborProductivity \times LaborExpenseRatio}{AverageCompensation \times TestingIntensity} \tag{6}$$

While this represents only one of many potential breakdowns of the return on investment measure, it has an advantage in that it addresses each of the categories from the functional form in (2) and has an appealing message to laboratory managers and stakeholders. Consider first the two items in the numerator. As either ratio increases, holding the other ratios constant, ROI increases. The first measure, labor productivity, is an efficiency measure. As workers become more productive and successfully complete more tests per person, the overall case output is increased. The second numerator ratio captures part of the analytical process for the laboratory. For most laboratories, personnel expense represents the highest category of expenses and provides more immediate returns in the present than expenditures toward capital. This suggests a mixed blessing. While the present return is higher from greater dedication of resources toward immediate application to casework (rather than investment in equipment for future application), there may be longer-term consequences that could reduce future ROI.

The two terms in the denominator capture market conditions and quality considerations. The higher the average compensation, the lower will be the return on investment. This proxy for market conditions is an important qualifier for inter-laboratory comparisons. The ROI for a laboratory is dependent upon local market conditions and, in markets with high cost of living, the forensic laboratory may have no choice in what it must pay as it competes with all other local industry for skilled employees. A forensic laboratory can't just decide to ignore the market or it will not be able to hire adequately. Alternative explanations for the size of this ratio then fall to other changes that may be related to the average compensation. See Dale and Becker (2004) for an examination of a change in the analytical process that has an impact on average compensation.

The other item in the denominator, the ratio of tests performed to cases analyzed, provides some indication of risk/quality management. Generally, when a laboratory conducts more tests for a given case, regardless of whether the number of tests is dictated by statute, policy, or practice, the increased testing will reduce the overall return on investment unless the additional testing can overly influence productivity. This last comment regarding the ROI expansion permits a more detailed analysis of proposed changes in risk management and begs the question as to whether a statutory requirement or policy shift in testing is worth the tradeoff on performance.

Notice that the inverse of expression (5) addresses a critical concern to forensic laboratories. The maximization of the return on investment (CASE/TOTEXP) is alternatively expressed as the minimization of the average cost per case for a given budget constraint. Inverting (5) we obtain:

$$\frac{TOTEXP}{CASE} = \frac{\frac{LEXP}{FTE} \times \frac{TEST}{CASE}}{\frac{TEST}{FTE} \times \frac{LEXP}{TOTEXP}} \tag{7}$$

Removing the notation and replacing with the definitions, expression (7) becomes:

$$\frac{AverageCost}{PerCase} = \frac{AverageCompensation \times TestingIntensity}{LaborProductivity \times LaborExpenseRatio} \tag{8}$$

This expression should appeal to the manager's common sense. When market conditions dictate that personnel expenses will be higher for a given service, average costs rise. As more tests for a case are conducted, costs will also rise. Turning to the denominator we also expect costs to fall as employees are more productive or when immediate resources are dedicated toward current period output rather than future investment.

ROI Expansion Applications

Because the ROI expansion is expressed entirely in ratios, forensic laboratories of any size may be compared via metrics easily collected on a regular (weekly, monthly, quarterly, or annually) basis. To illustrate, consider three fictional forensic laboratories and their information from records of casework, personnel, and budgets. Note that the analysis presented in the previous section can be applied to the entire laboratory or to individual investigative areas within a forensic laboratory. Because the mission, location, or other choices of each forensic laboratory may call for differences in services provided and in the intensity of those activities within the overall laboratory, the

Table 1. Key Laboratory Metrics

Fingerprint Identification	*Laboratory S*	*Laboratory M*	*Laboratory L*
Cases Processed (CASE)	1,150	3,050	9,650
Total Expenditures (TOTEXP)	\$175,000	\$715,000	\$3,900,000
Personnel Expenditures (LEXP)	\$155,000	\$445,000	\$3,075,000
Full-time Equivalent Employees (FTE)	2.00	5.35	33.00
Tests Performed (TEST)	4,100	14,300	58,300

analysis for a single investigative area is highlighted in the example to follow.

The three laboratories, S, M, and L, each have some common investigative areas, but differ in the total investigative services rendered. Because of the different scope of services, a laboratory-wide comparison of the ratios would be difficult to interpret. However for a common investigative area for each laboratory, a meaningful comparison can be obtained. Suppose for this example that each of these three forensic laboratories has a fingerprint identification section. (Appendix B defines each of the investigative areas from the QUADRUPOL and FORESIGHT studies and includes the select area, fingerprint identification.) For the fingerprint identification investigative area, the three laboratories' data are reported in Table 1.

Direct comparison is very difficult, given the different sizes for the three forensic laboratories, but conversion to ratios can enable a worthwhile comparison. Although laboratory L processes more than eight times as many cases laboratory S, it does so with a substantially larger budget. Using the ROI measure defined in (1), we find:

$ROI_S = 0.0066$ cases per dollar or an average cost per case of \$152.17;
$ROI_M = 0.0043$ cases per dollar or an average cost per case of \$234.43; and
$ROI_L = 0.0025$ cases per dollar or an average cost per case of \$404.15.

Using either the return on investment or the average cost measure suggests a much higher level of performance for laboratory S versus its larger counterparts. It is somehow able to do much more with its limited resources. The ROI measures indicate for these three laboratories that the larger the laboratory, the lower the return. Is this an indication of economies of scale or is it something else? Breaking down the data into the components described by (8) for average cost per case reveals more useful information for the comparison of the laboratories (Table 2).

The decomposition of the average cost per case ratio into the four component costs begins to reveal the reasons for the differing performances for the three laboratories. First, when average compensation (LEXP/FTE) is higher, so is average cost per case. This is partly a product of market conditions. That is, higher cost of living environments tend to also have a higher salary scale, and the laboratory cannot ignore local economic conditions, hence higher costs for operations.

Of course market conditions alone do not fully explain the disparity in the average compensation. Other supporting explanations for higher compensation include greater productivity or a different mix of scientists, analysts, and support staff. The greater productivity argument appears to be at play in this case for some of the laboratories. Consider the ratio for personnel productivity (TEST/FTE) in the fifth column. The average compensation for laboratory M is higher than the average compensation for laboratory S, but this seems to be justified by the relatively higher productivity of the staff at laboratory M. For laboratory L, however, these two columns raise a red flag as Laboratory L pays the highest compensation but has the least productive workers of the three laboratories. Here the decomposition points to an area for greater inspection.

The testing intensity ratio (TEST/CASE) also appears to be directly related to the average cost per case. Higher testing is used as a proxy for risk—the more tests for a case, the lower the risk of an error of commission and the higher the quality assurance. That additional testing comes at a cost and increases the average cost per case. The increased testing also has indirect costs, potentially increasing errors of omission, as backlog is increased *ceteris paribus* with additional testing. As with the market measure, the full explanation likely involves more than just risk. Greater testing may also be reflective of greater complexity to an average case or to other variables. There is a large disparity in the testing behavior of these three laboratories. Again, a red flag is raised with the substantially lower testing level (and resultant lower average cost)

Table 2. Ratio Expansion

	Average Cost per Case	*Average Compensation*	*Testing Intensity*	*Personnel Productivity*	*Labor Expense Ratio*
Laboratory S	\$152.17	\$77,500	3.57	2,050	88.57%
Laboratory M	\$234.43	\$83,178	4.69	2,673	62.24%
Laboratory L	\$404.15	\$93,182	6.04	1,767	78.85%

for laboratory S and substantially higher testing level of laboratory L. Is the former laboratory cutting corners or is it simply more efficient? And is the latter laboratory testing too much? Are there statutory reasons, policies, or practices that call for the testing levels? The differences beg explanation and should be investigated.

The labor expense ratio (LEXP/TOTEXP), coupled with the other ratios, helps to complete the picture of the performance differentials. This measure suggests that laboratory S dedicates most of its expenditures for the here and now, and reserved very little in this year for investment in the future via capital expenditures. Laboratory M appears to be doing just the opposite with much smaller allocations to current period expenditures in the form of personnel expenses. While it could indicate some differential in analytical process via a more capital-intensive practice by laboratory M, it is more likely there are differences in capital expenditures. Since investment in equipment occurs at discrete times, while personnel expenditures are continuous, this ratio should always be checked alongside the average cost measure. Laboratory M might just be better at writing grants for equipment, but since it doesn't spread out the capital expense over time, it gives an appearance of more costly behavior.

In summary, if a review of a laboratory was limited to the ROI or average cost per case measure, then it might be concluded that laboratory S was the top performer among the three laboratories analyzed. However, the decomposition of these measures into the four component ratios points to specific areas for greater investigation before anointing laboratory S the best performer. While laboratory S seems reasonably efficient in its operations, it has been able to reduce costs by investing less in its future than the other laboratories and testing at a lower rate, perhaps sacrificing quality. Laboratory L is the most expensive laboratory and the decomposition offers several reasons why that is so. Laboratory L offers exceptionally high salary and benefits, has a less productive staff than the other laboratories, and may be testing more than necessary for the average case. All of these contribute to a poor relative performance and calls for a close review of policies, practices, and procedures. Laboratory M, on the other hand, appears to be the laboratory whose practices are exemplary. Personnel are paid a little more than the smaller laboratory, but those payments seem to be justified with a high level of productivity. Laboratory M also appears to be investing in its future with greater capital expenditures, which should enable a lowering of average costs in future periods.

Concluding Remarks

Ratio metrics provide a quick and convenient mechanism by which to track performance for a laboratory and a means by which to compare that performance with best practices within the industry. The ease of use comes with a caution to not rely solely on a single performance measure. Rather, a series of measures may be used to paint the full performance picture. The decomposition of the return on investment ratio or the average cost per case ratio shows that these performance metrics can be presented as a combination of metrics relating outcomes to efficiency, risk, analytical process, and market conditions.

The calculation of these ratio metrics can be performed on a regular basis across each investigative area within the laboratory and compared over time and across the industry. As such, they offer a simple, yet highly informative tool for a laboratory manager to use on a regular basis. The measures also point to areas of future research as information from high-performing laboratories is cataloged and the performance stories are shared with the rest of the industry. The decomposition presented above offers a foundation to share those stories.

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Appendix A: Nomenclature Established by QUADRUPOL and U.S. Foresight Projects

Assistant/Analyst An individual carrying out general casework examinations or analytical tests under the instruction of a Reporting Scientist or Reporting Analyst and who is able to provide information to assist with the interpretation of the tests.

Backlog Open cases that are older than 30 days as measured at the end of the year.

Case - Institute Case A request from a forensic laboratory "customer" that includes forensic investigations in one or more investigative areas.

Case - Area Case A request for examination in one forensic investigation area. An area case is a subset of an institute case.

Casework All laboratory activities involved in examination of cases.

Casework Time Total FTEs for the operational personnel in the investigation area (in hours) subtracted by the hours of R&D, and E&T and support and service given to external partners.

Crime A perceived violation of the law that initiates a case investigation.

Direct Salary Total salary paid to employees, including overtime compensations, vacation salary, bonuses, etc.

Examinations (Exams) The word QUADRUPOL used for "test"; see both "test" and "sample" in this glossary for the changes adopted by U.S. Foresight.

Facility Expense Sum of rents, cleaning and garbage collection, security, energy, water, communication, ICT infrastructure, and facility maintenance.

Floor Area Total of all floor area including office, laboratory and other.

Full-Time Equivalent (FTE) The work input of a full-time employee working for one full year.

Full-Time Researcher A forensic scientist whose primary responsibility is research and who is not taking part in casework.

Investigation Area Area limited by item type and methods as they are listed in the benchmarking model.

Investment Expense Sum of purchases of equipment, etc., with a lifetime longer than three years and a cost above $1,000 (alternatively capital expenses).

Item A single object for examination submitted to the laboratory. Note: One item may be investigated and counted in several investigation areas.

Laboratory Area Floor area used for forensic investigation, including sample and consumable storage rooms.

Non-Reporting Manager An individual whose primary responsibilities are in managing and administering a laboratory or a unit thereof and who is not taking part in casework.

Office Area Floor area of offices (square feet).

Operational Personnel Personnel in operational units providing casework, research and development (R & D), education and training (E & T), and external support services. Non-reporting unit heads are included.

Other Area Floor area of space not belonging to laboratories or offices, i.e., corridors, lunch corners, meeting rooms, etc. (square feet).

Overhead Time Total FTEs in hours in the investigation area subtracted by the total hours of casework, R&D, E&T, and support and service given to external partners.

Personnel Expense Sum of direct salaries, social expenses (employer contribution to FICA, Medicare, workers' comp, and unemployment comp), retirement (employer contribution only towards pensions, 401(k) plans, etc.), personnel development and training (internal or external delivery, including travel), and occupational health service expenses (employer contribution only).

Report A formal statement of the results of an investigation, or of any matter on which definite information is required, made by some person or body instructed or required to do so.

Reporting Analyst An analyst is responsible in non-complicated cases (e.g., simple drugs analysis) for performing the examination of the items submitted, interpreting the analysis results, writing the analysis report and, if necessary, providing factual evidence for the court.

Reporting Scientist The forensic scientist responsible in a particular case for performing or directing the examination of the items submitted, interpreting the findings, writing the report, and providing evidence of fact and opinion for the court.

Representation Expense The costs for hosting guests, i.e., lunches, dinners, coffees offered by the lab, and presents given to guests or during visits abroad, etc.

Running Operational Expense Other costs than investment costs, personnel costs, and facilities costs, e.g., consumables, traveling, QA, literature, contracting, representation, service and maintenance, information and advertisement.

Sample An item of evidence or a portion of an item of evidence that generates a reported result.

Scientist in Training An individual with no reporting rights being trained to become a reporting scientist.

Student Hours The sum of teaching hours in a course multiplied by the number of students attending the particular course.

Support Personnel Forensic laboratory staff providing various internal support services. Management and administration personnel not belonging to the operational units are included.

Teaching Hours Time spent teaching in the lecture room in hours (60 minutes).

Test An analytical process including, but not limited to, visual examination, instrumental analysis, presumptive evaluations, enhancement techniques, extractions, quantifications, microscopic techniques, and comparative examinations. This does not include technical or administrative reviews.

Total Expense The sum of the direct expenses (personnel, operating, and investment) and any administrative or other overhead expenses.

Total Funding The sum of all funding sources including jurisdictional budgeting, grant awards, bequests, and revenue sources.

Total Items Includes all items to which the laboratory assigns an item or tracking number. This is different than the number of items the laboratory receives (the laboratory may split items up for analysis).

Workload Total time spent on all work related to job, including overtime.

Appendix B: Definition of Investigation Areas From the QUADRUPOL and U.S. FORESIGHT Projects

Accident Investigation All non-traffic accident investigations, such as work-related accidents.

Biology (Non-DNA) The detection, collection, and non-DNA analysis of biological fluids.

Blood Alcohol The analysis of blood or breath samples to detect the presence of and quantify the amount of alcohol.

Computer Analysis The analysis of computers, computerized consumer goods, and associated hardware for data retrieval and sourcing.

Crime Scene Investigation The collection, analysis, and processing of locations for evidence relating to a criminal incident.

Digital Evidence - Audio & Video The analysis of multimedia audio, video, and still-image materials, such as surveillance recordings and video enhancement.

DNA Casework Analysis of biological evidence for DNA in criminal cases.

DNA Database Analysis and entry of DNA samples from individuals for database purposes.

Document Examination The analysis of legal, counterfeit, and questioned documents, excluding handwriting analysis.

Drugs - Controlled Substances The analysis of solid dosage licit and illicit drugs, including pre-cursor materials.

Entomology Forensic entomology is the application of the study of arthropods, including insects, to criminal or legal cases.

Evidence Screening & Processing The detection, collection, and processing of physical evidence in the laboratory for potential additional analysis.

Environmental analysis The analysis of naturally occurring materials, such as soil or water, for foreign substances with criminal implications.

Explosives The analysis of energetic materials in pre- and post-blast incidents.

Fingerprints The development and analysis of friction ridge patterns.

Fire Analysis The analysis of materials from suspicious fires to include ignitable liquid residue analysis.

Firearms & Ballistics The analysis of firearms and ammunition, to include distance determinations, shooting reconstructions, NIBIN, and toolmarks.

Forensic Engineering & Material Science Failure and performance analysis of materials and constructions.

Forensic Pathology Forensic pathology is a branch of medicine that deals with the determination of the cause and manner of death in cases in which death occurred under suspicious or unknown circumstances.

Gun Shot Residue (GSR) The analysis of primer residues from discharged firearms (not distance determinations).

Hairs & Fibers The analysis of human and animal hairs (non-DNA) and textile fibers as trace evidence.

Handwriting The evaluation of handwritten materials to categorize or identify a writer.

Marks & Impressions The analysis of physical patterns received and retained through the interaction of objects of various hardness, including shoeprints and tire tracks.

Odontology The identification of human remains through dental materials, for example by postmortem X-rays of the teeth compared to antemortem X-rays. Some forensic odontologists also analyze and compare bite marks.

Paint & Glass The analysis of paints—generically, coatings—and glass as trace evidence.

Road Accident Reconstruction Analysis of criminal incidents involving vehicles and accidents (hit and run, for example).

Speech & Audio The analysis of live and recorded vocalizations in criminal investigations.

Toxicology, Antemortem Toxicology involves the chemical analysis of body fluids and tissues to determine if a drug or poison is present in a living individual, to include blood alcohol analysis (BAC).

Toxicology, Postmortem Toxicology involves the chemical analysis of body fluids and tissues to determine if a drug or poison is present in a deceased individual.

Trace Evidence The analysis of materials that, because of their size or texture, transfer from one location to another and persist there for some period of time. Microscopy, either directly or as an adjunct to another instrument, is involved.