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Process Improvement and the Efficient Frontier: Forecasting the Limits to Strategic Change across Crime Laboratory Areas of Investigation

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ABSTRACT

Undertaking programs for process improvement, such as Lean Six Sigma, permit a laboratory to do more with their limited resources. The Netherlands Forensic Institute (NFI) embraced a Lean Six Sigma change process that led to dramatic increases in capacity, while simultaneously reducing turnaround time (TAT) to a fraction of their historical experience. As other laboratories adopt similar process improvement programs, will those laboratories also experience similar results with higher productivity across the laboratory and reduced turnaround time in every area of scientific investigation? We demonstrate that similar success may be expected with a laboratory's current caseload, but the degree of improvement is related to the size of the political jurisdiction, crime rates, and the resulting caseload; and the degree of inefficiencies at the start of the process improvement program. An understanding of the economic forces at play enables laboratory management to better forecast outcomes and plan for the eventualities. Using data from Project FORESIGHT 2015–2016, tables are provided that permit laboratories to match their caseload within each area of investigation to the forensic laboratory standard for efficiency at that caseload.

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Introduction

The Netherlands Forensic Institute (NFI) embraced a Lean Six Sigma change process that led to dramatic increases in capacity, while simultaneously reducing turnaround time (TAT) to a fraction of their historical experience (van Asten 2014; Tjin-A-Tsoi 2013). The adoption of a Lean Six Sigma strategy by NFI was aligned with the mandates of the National Academies of Science report (NAS 2009). Pressure upon the NFI, as with forensic laboratories worldwide, was evidenced by greater demands for services without corresponding increases in resources to meet those demands. As a response, they took a customer-centric approach towards process improvement as a means to respond to the widening gap between customer demands and available resources.

The account of the NFI process improvement (van Asten 2014) includes the prospects for further gains via innovation in forensic science research and offers some grand challenges for further improvements (some challenges which have already been addressed elsewhere (Castillo-Peinado and de Castro 2016). In this article, we offer observations and analysis to complement the observations of the NFI experience through insights into the economic foundations that provide direction into the forecasting of results from such process improvement. Economics is a social science guided by laws; and rudimentary knowledge of the workings of the affiliated laws enables laboratory management to better prepare for the resulting change from strategic initiatives. From those economic foundations, econometric modeling of performance across laboratories in the forensic sciences leads to an estimation of the efficient performance possibilities for the caseload of a particular jurisdiction. A laboratory's comparison of its own performance to the efficient frontier defines the gap that may be overcome through strategic changes for process improvement.

The end game is a moving target. The change process is dynamic and all too often planners mistakenly prepare for a static environment. By understanding the underlying forces at work, laboratory management

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may use that knowledge to more accurately forecast the outcomes from strategic initiatives. Process improvement also affects the expectations of customers and the resulting demand for laboratory services. Improved forecasts of the customer response will permit the laboratory and its parent funding body to be forewarned and forearmed to best meet the growing demands for its services with the limited resources at its disposal.

There are both direct and indirect predictable effects from process improvement. The indirect consequences need not be surprising; they can be estimated and anticipated in the planning process and the corresponding planning can and should be conducted (Houck 2017). The NFI Lean Six Sigma initiative began with a concentration on the existing level of services and the initiation of process improvement. Too often, however, the initial planning treats potential efficiency gains as a static process. That is, the planning considers the current demands upon the system and self-reflects on how to handle that load better. But the process of "doing it better," has its own effect on the demand for services, because success breeds success as process improvement leads to higher laboratory case throughput and reduced turnaround time (TAT). The planning strategy must include a consideration for the increased requests for testing of current cases and the increase in the number of cases brought to the laboratory as TAT is reduced. The dynamic problem comes in different forms. It includes the higher demand from existing and new cases, but must also deal with the resulting economies or diseconomies of scale.

The complexity of the problem requires planners to first address the inefficiencies associated with the current scale of operations and consider the efficiency gains that might come to that level of output from a productivity improvement process such as a Lean Six Sigma program. The immediate impact from a process improvement program is an increase in output for a given level of expenditures, but that improved performance will have an associated reduction in TAT for casework. Any decrease in TAT triggers a response from the requestors of laboratory services, which can be predicted using a metric, the queuing elasticity of demand. The queuing elasticity of demand suggests the level of demand for services facing the laboratory for any associated TAT. Using forensic industry data, it is possible to estimate the target level of services and associated cost per service that can be expected from achieving greater economies of scale. Using experiential data, the laboratory can begin to anticipate the moving target set in motion by process improvement and then anticipate the outcomes and societal benefit from its internal process improvement activity. Thus, armed with greater forethought of its actions, the laboratory may be better served to meet its mission and to argue effectively for the funding necessary to complete its mandate.

In the sections that follow, we begin with an introduction to a few key economic forces at play for the provision of any good or service, including the services of the forensic laboratory. Following the description of these basic economic forces, a few key performance ratios and their interrelationships are discussed along with data from Project FORESIGHT (Houck. et al. 2009) to illustrate the key behaviors. The econometric model alternatives are introduced and demonstrated for one area of investigation, DNA Casework, and the corresponding tables for efficient performance at various jurisdictional caseloads is presented. A section follows with the tabular representation of the efficient frontier for other areas of investigation follows with corresponding econometric estimates in the Appendix. Concluding comments complete the discussion.

Economic principles and laws in economics

As with the physical sciences, economic behavior is ruled by some immutable laws. Among these laws are two that are relevant to the topic at hand, the Law of Demand and the Law of Diminishing Marginal Returns (LDMR). Understanding the Law of Demand is critical to strategic initiatives that result in changes in the rationing device for scarce resources (e.g., price or wait time). A change in the level of the rationing mechanism will change the quantity of services demanded in response to that change stimulus. The Law of Demand in a for-profit marketplace references price as the rationing mechanism, where the provider continues to raise or lower the price of a service until a level is reached where the quantity of services demanded at that price is equal to the quantity of serves provided. However, the allocation of forensic science services is rarely rationed by price; forensic science services are treated as a "free" service in most situations (Tjin-A-Tsoi 2013). Instead, wait time serves to allocate services and an understanding of a corollary to the Law of Demand with queuing time or TAT replacing price is pertinent to the present discussion.

The Law of Diminishing Marginal Returns may be directly applied from economic theory to the workings of the forensic laboratory. In the provision of any good or service, as more of a particular input is added to a production process, eventually a point is reached where increases in production occur at a diminishing rate. LDMR principles are imbedded in the concepts of economies and diseconomies of scale. That is, there is an ideal scale of operations in the production of any good or service. In the for-profit world, market forces mold businesses into the "right" size, where average total costs of production are minimized and all businesses in a given industry tend towards that ideal size; otherwise they are priced out of business. Without price competition in jurisdictionally based service areas to force forensic laboratories to adjust their size to a cost-minimizing level, there remain untapped economies of scale to experience via expansion of operations (Maguire et al. 2012b). It is critical to the effective planning by the laboratory to understand the magnitude of the reactions of consumers of forensic science services via the Law of Demand and to realize production realities regarding efficiency and cost effectiveness for the laboratory as services are expanded.

Economies of scale and LDMR

A consideration of economic theory in the production of goods or services involves both a sense of efficiency and cost effectiveness. Efficiency refers to the selection of a production process that is best for a given level of activity. The reference to "best" suggests adoption of the cost minimizing process that maintains a given quality standard. The combination of capital and personnel best suited to analyze a small number of cases will be different from the amount and mixture of capital and personnel to analyze a caseload that is ten times larger. Given time, laboratories will gravitate towards the process that permits the greatest amount of case processing (while maintaining quality standards) for the budget at their disposal. With knowledge of LDMR, laboratories are able to expand or contract the use of capital and personnel to find lowest cost alternatives to process a given number of cases.

Process improvement programs, such as Lean Six Sigma, may have a significant impact upon a laboratory's efficiency by identifying the means to make a faster adjustment to the optimal process. However, the degree of success that a laboratory might achieve from a process improvement agenda is limited by the laboratory's relative efficiency prior to consideration of a change process. For a laboratory to achieve success from such a process change program, it must begin from a position of inefficiency if it is to expect gains similar to those achieved by NFI.

Economic theory indicates that as the level of output increases, the average cost to produce that output will fall and the output per dollar spent will increase up to a level of perfect economies of scale; thereafter higher output will result in lower rates of output per

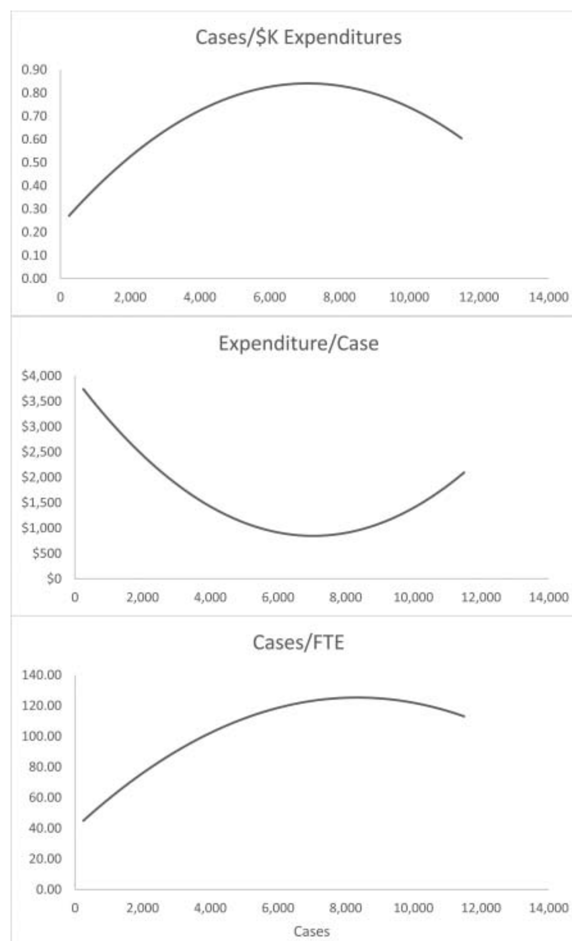

Figure 1. The efficient frontier, average cost, and productivity about here.

expenditure and an associated higher average cost of processing. Figure 1 illustrates this theoretical relationship. The hump-shaped upper graphic demonstrates the rise in output/expenditure as output increases up to the point of perfect economies of scale. When a laboratory is able to produce at a point along the curve, it exhibits efficient production. That is, given its level of casework, a laboratory that is able to reach a point along this "efficient frontier" has provided the best relative output that can be expected. The inverse of that metric, the average cost is illustrated in the second graph with a U-shaped curve. Along the downward portion of the curve we experience greater economies of scale as the caseload increases, but beyond the minimum point, diseconomies of scale are experienced as highlighted in the upward-sloped portion of the curve. The bottom graphic illustrates the relationship between these curves and productivity within the laboratory, where productivity is illustrated as the number of cases processed per full-time equivalent employee (FTE). The rise in productivity that is experienced with reaching the optimal output size is directly related to the changes in average cost of providing that output.

Considerations of efficiency refer to positions along the efficient frontier. Since most laboratory operations are limited to the boundaries of its political jurisdiction, comparisons of a laboratory's performance to the efficient frontier is the most relevant comparison to be made. Cost effectiveness, on the other hand, refers to the point of perfect economies of scale, the maximum point of the upper graph in Figure 1 or the minimum point of the middle graph.

Law of demand

The law of demand recognizes the relationship between the price per unit and the number of units demanded by consumers at each possible price, while holding all other demand influences constant. The price vs. quantity relationship emphasized in the law of demand, indicates that as prices rise, then eventually a price level is reached where the quantity demanded falls. Put simply, there is an inverse relationship between price and the quantity demanded. That relationship between price (P_{own}) and quantity demanded is determined by individuals for given levels of income, wealth, tastes & preferences, and prices of substitute (P_{sub}) or complentary (P_{comp}) goods or services.

$$Q_d = f(P_{own}, Income,\ Wealth,\ Tastes,\ P_{sub}, P_{comp}) \tag{1}$$

In the for-profit world, producers realize that when they lower price, they expect to sell more units of a good or service; conversely, if they raise price, they expect to sell fewer units. Price serves as a rationing mechanism to allocate scarce resources. While the law of demand indicates the direction of the change in quantity demanded from a given change in price, it does not indicate the magnitude of the change in quantity demanded. The magnitude of the change is more of a reflection of the attitudes of the consumer and the nature of the product of service being offered for sale. Economists use a metric, price elasticity of demand, to predict the impact of a given change in price on the quantity demanded. While the law of demand dictates that a price decrease will result in an increase in quantity demanded, the price elasticity of demand metric permits forecasters to predict whether such a price cut will result in a large enough quantity demanded increase to offset the price decline and lead to an increase in revenue.

Price elasticity of demand:

$$\eta_{price} = \frac{\text{percentage change in } quantity\ demanded}{percentage\ change\ in\ price} = \frac{\partial Q_d}{\partial P}\frac{P}{Q_d} \tag{2}$$

Because of the inverse relationship between price and quantity demanded in the demand schedule, η_{price} is a negative number. When $-1 < \eta_{\text{price}} < 0$, then demand is said to be inelastic; that is the percentage change in quantity demanded is small relative to the percentage change in price. A price increase is met with an increase in total revenue (price multiplied by quantity). Conversely, a price decrease would be met by a decline in total revenue. If $\eta_{\text{price}} < -1$, then demand is termed elastic; that is, there is a larger percentage change in quantity demanded than the initiating percentage change in price and an increase in price is met by a decrease in total revenue, while a decrease in price is met by an increase in total revenue.

The price elasticity of demand may be estimated by tracking discrete changes in price and observing the corresponding change in quantity demanded.

$$\textit{Price elasticity of demand: } \eta_{price} = \frac{\%\Delta Q_d}{\%\Delta P} \qquad (3)$$

For most forensic science laboratories, there is no explicit price for its services and those services must be rationed by some other mechanism. Often, wait time (as measured by TAT) becomes the rationing mechanism in place of price. If the queue is too long, some cases are never submitted to the laboratory or if submitted, the requests may be limited to a subset of potential items of evidence. However, when a laboratory is able to successfully reduce its TAT, then that serves as a signal to its customers. Laboratory customers respond with an increase in requests to the laboratory. TAT serves much like price as the rationing mechanism. Reactions to changes can be represented by a queuing elasticity of demand.

$$\textit{Queuing elasticity of demand:}$$

$$\eta_{TAT} = \frac{\%\Delta \textit{ quantity demanded}}{\%\Delta \textit{ TAT}} \qquad (4)$$

As with the law of demand and price, we know that a reduction in TAT will result in an increased quantity demanded, but η_{TAT} provides an indication of the magnitude of the reaction via quantity demanded to a change in the stimulus.[1]

Economies of scale, demand elasticity, process improvement, and implications for forensic laboratories

For most public sector forensic laboratories, the services of the laboratory are treated as "free" to the customers of the laboratory. Notable exceptions are The Netherlands NFI [(van Asten 2014) and (Tjin-A-Tsoi 2013)] and New Zealand's Institute of Environmental Science and Research (ESR) (Bedford 2011) and (Speaker 2013), where service agreements place the funding in the hands of the corresponding policing organizations who purchase the services of the forensic science provider. For most remaining forensic providers, the users of their services have a seemingly unlimited demand for services which is held in check by the queuing time for the receipt of those services.

Will all laboratories have the same experience as the NFI following a process improvement program? What can a laboratory considering the adoption of a process improvement program expect to experience? As the discussion above suggests, the success is highly dependent upon the starting point. Consider laboratories X, Y, and Z highlighted in Figure 2.

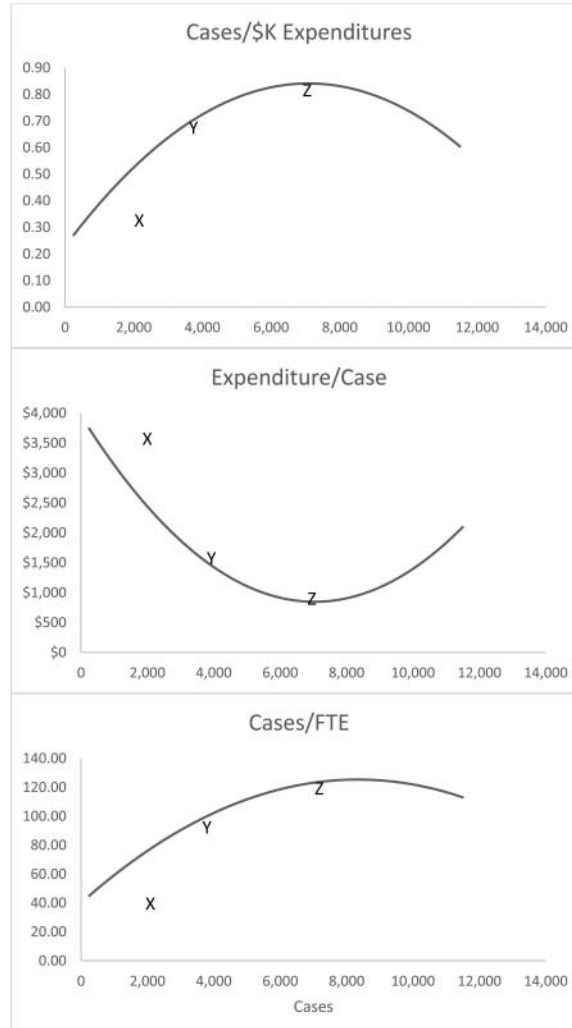

Figure 2. Process improvement, efficiency, and cost effectiveness.

Laboratory X begins at a point of inefficiency; that is, for its caseload, it falls below the Cases/$K Expenditures of the efficient frontier in the upper graph and above the efficient average cost in the middle graph. The bottom graph shows that the productivity metric, Cases/FTE, falls below what is possible for that caseload. A process improvement program offers the possibility of higher productivity to be met with a reduction in average cost and a corresponding increase in the inverse of that metric, Cases per thousand dollars of expenditures. But the case output would not be expected to be static for laboratory X. As output productivity increased, given the same level of resources, TAT would decline, prompting an increase in the quantity demanded for casework that could be anticipated from the queuing elasticity of demand from estimation of Equation (4). Thus, laboratory X would not only move closer to the efficient frontier, but would also experience a move along the frontier towards laboratory Y's mapping in each of the graphs.

Laboratories Y and Z, however, originate at positions of efficiency. Laboratory Y, although not operating at perfect economies of scale, is experiencing an efficient output for its caseload and no gap in productivity improvement is foreseen. All things equal, a program designed for process improvement would prove to be futile. Any attempt to achieve greater economies of scale would require activity beyond that level dictated by its jurisdiction. Laboratory Z begins from the strongest point where they experience both efficiency and cost effectiveness with perfect economies of scale. A program aimed at process improvement would be fruitless.

Decomposition of returns

Crime laboratories face the challenge of greater public expectations of the capabilities of forensic science (both real and imagined) to assist in the administration of justice. Connecting strategic actions to potential gains has been suggested previously in the literature. This includes considerations of what to measure (Speaker 2009a), how to interpret the measures [(Speaker 2009b) and (Speaker and Fleming 2010)], and implementation of a change process (Newman, Dawley, and Speaker 2011). More recently, a refinement in the decomposition of returns was suggested following an examination of Canadian forensic science laboratories (Maguire et al. 2012a; Houck et al. 2015). Refinements from traditional interpretations are necessary because of the differences in economic forces at play between market economies and political jurisdictions (Houck et al. 2015; McAndrew and Roth 2016).

Following the caveats regarding standards for quality (van Asten 2014), forensic laboratories attempt to optimize their processing of casework given their budget constraints. A decomposition process takes the objective function and breaks it down into a series of relevant ratios to explain behavior. These ratios are formed by multiplying the optimization ratio CASES/TOTEXP (Cases processed divided by total expenditures) by the number one in various formats (Speaker 2009b). Since productivity and market forces have been identified as determinants of laboratory performance, we perform an expansion of the objective function to include consideration for these explanations of performance.

$$\frac{CASES}{TOTEXP} = \frac{CASES}{TOTEXP} \times \frac{PEXP}{PEXP} \times \frac{FTE}{FTE}, \quad (5)$$

where CASES represents cases processed, TOTEXP is the Laboratory's total expenditures, PEXP is the expenditure for personnel, and FTE is the number of full time equivalent employees. Recombining terms yields:

$$\frac{CASES}{TOTEXP} = \frac{CASES}{FTE} \times \frac{PEXP}{TOTEXP} \times \frac{FTE}{PEXP} = \frac{\frac{Cases}{FTE} \times \frac{PEXP}{TOTEXP}}{\frac{PEXP}{FTE}} \quad (6)$$

CASES/FTE is a productivity measure that captures the average number of cases processed per person. *PEXP/TOTEXP* provides a percentage of expenditures that are spent on personnel and capture spending for the current period rather than investment in capital for future output. *PEXP/FTE* is a market measure that captures local economic market forces and the average compensation per person in the laboratory. Thus,

$$\frac{CASES}{TOTEXP} = \frac{Productivity \times Percentage\ of\ Expenditures\ on\ Personnel}{Average\ Compensation} \quad (7)$$

This breakdown suggests that the potential gains to output may be affected by several sources and understanding the potential contribution from each source will enhance the predictability of any strategic change.

The efficient frontier

The potential for gain from process improvement depends upon the starting point of a forensic laboratory, both with respect to efficient operation and with respect

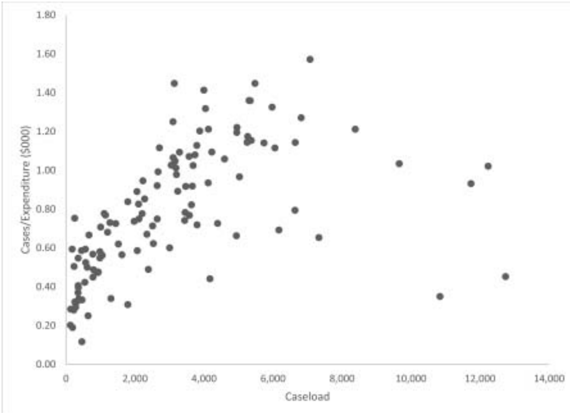

Figure 3. DNA casework—cases/expenditures vs. caseload.

to caseload and economies of scale. To illustrate, consider DNA Casework using 2016 fiscal year data from Project FORESIGHT (Houck et al. 2009) in Figure 3.

Economic theory indicates that the relationship between output per expenditure versus size of the operation should be a hump-shaped curve (an inverted U). The inverse of this is a U-shaped economies of scale curve relating average total cost to output level. Perfect economies of scale are associated with the peak of the output per expenditure curve and the trough of the average cost curve (i.e., the most efficient sized laboratory). Figure 4 fits such a Cases per Expenditure curve to the data using a quadratic regression.

$$\frac{Cases}{Expenditures} = \beta_0 + \beta_1 Cases + \beta_2 Cases^2 + error \tag{8}$$

The significance of this relationship may be found in separation between the efficiency for a given level

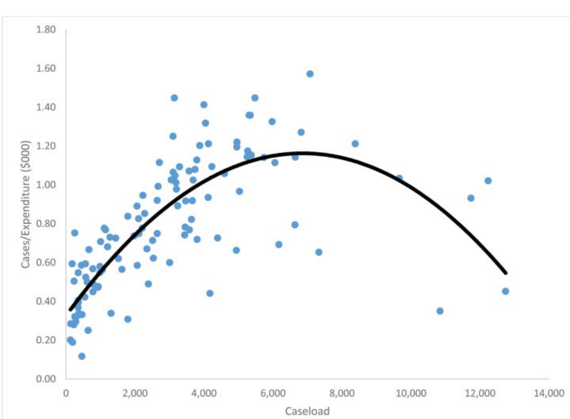

Figure 4. DNA Casework efficient frontier—cases/expenditures vs. caseload.

of activity (caseload) and the fitted curve representing efficiency for that given caseload. The fitted curve offers a sense of the output that can be expected for a given caseload. While a for-profit industry could be expected to see surviving firms produce at an output level associated with the peak of the curve, a jurisdictionally-based enterprise ordinarily is limited to the level of output supported by its jurisdictional boundaries. The efficient frontier maps the associated efficient level of cases per thousand dollars expended for the jurisdiction's caseload. The greater is the distance that a laboratory falls below the efficient frontier, then the greater is the potential gains from a process improvement program. On the other hand, a laboratory that currently performs on or near the efficient frontier is not expected to be able to gain much, if any, from such a program. Thus, before undertaking a program of change, laboratory management should assess what might be gained and whether the cost justifies the benefits from the planned "process improvement" program.

While economic theory proscribes the shape of the efficient frontier, it is possible that the data supporting the estimate of the frontier merely represents a portion of the efficient frontier. That would certainly be the case if jurisdictional restrictions never reach a size consistent with perfect economies of scale. If that were the case, then alternative nonlinear estimations should be considered to capture the downward-sloped portion of the curve. Equation (9) offers on potential estimation using a logarithmic model.

$$\frac{Cases}{Expenditures} = \beta_0 + \beta_1 LN(Cases) + error \tag{9}$$

Alternatively, a double logarithmic model, as highlighted in equation (10), may also approximate the downward-slopted portion of the curve.

$$LN\left(\frac{Cases}{Expenditures}\right) = \beta_0 + \beta_1 LN(Cases) + error \tag{10}$$

Finally, to offer a point of comparison, a linear model may be considered as highlighted in

Equation (11)

$$\frac{Cases}{Expenditures} = \beta_0 + \beta_1 Cases + error \quad (11)$$

Note that the traditional economies of scale interpretation of the performance across levels of output is the inverse of the left-hand-side ratio in Equation (4). Rather than the maximization of Cases per Thousand Dollars Expended, consider the minimization of the inverse Cost/Case.

$$\frac{Cost}{Case} = \alpha_0 + \alpha_1 Cases + \alpha_2 Cases^2 + error \quad (8.1)$$

Likewise, the relationships expressed in Equations (9) and (10) may be restated with respect to the inverse ratio, Cost/Case as expressed in Equations (9.1) and (10.1).

$$\frac{Cost}{Case} = \beta_0 + \beta_1 LN(Cases) + error \quad (9.1)$$

$$LN\left(\frac{Cost}{Case}\right) = \beta_0 + \beta_1 LN(Cases) + error \quad (10.1)$$

Since the estimation of (8.1), (9.1), and (10.1) are open to easier interpretation, these equations are estimated in the following section for DNA Casework. The results for additional areas of investigation are presented in the Appendix.

While the quadratic, logarithmic, and double logarithmic relationships in Equations (8), (8.1), (9), (9.1), (10), or (10.1) offer relatively simple measurements of the efficient frontier, more detailed econometric analysis might offer greater insight, particularly at the extreme high and low caseloads (Henrik, Paldam, and Wurtz 2007). The use of these estimations offers individual laboratories a quick response for analysis of their present situation and a sense of potential gains from a process improvement program.

Estimation of the efficient frontier

To demonstrate how a laboratory might evaluate its present situation and determine whether a process improvement program is worthwhile, we estimate the efficient frontier using 2015–2016 data from Project FORESIGHT. For the 2015–2016 submission year, 139 laboratories worldwide submitted data. The submissions included detailed casework data across nineteen investigative areas and financial data offering a sense of the fully loaded costs to the laboratory including expenditures for personnel, capital, consumables, overhead, and all other direct and indirect costs. Table 1 provides the quartile measures for each of the areas of investigation for the Project FORSIGHT 2015–2016 submissions.

Table 1. Cases per $1,000 expenditures by investigative area.

Area of Investigation	25th percentile	Median	75th percentile
Blood Alcohol	4.34	8.13	11.12
Crime Scene Investigation	0.15	0.25	1.26
Digital evidence - Audio & Video	0.17	0.31	0.64
DNA Casework	0.52	0.75	1.06
DNA Database	6.04	13.50	16.87
Document Examination	0.16	0.29	0.45
Drugs - Controlled Substances	2.36	3.20	4.43
Evidence Screening & Processing	0.56	0.85	2.06
Explosives	0.05	0.08	0.15
Fingerprints	1.03	1.45	2.04
Fire analysis	0.34	0.54	0.95
Firearms and Ballistics	0.33	0.57	1.09
Forensic Pathology	0.33	0.50	0.62
Gun Shot Residue (GSR)	0.28	0.43	0.64
Marks and Impressions	0.11	0.16	0.36
Serology/Biology	0.43	0.68	1.24
Toxicology ante mortem (excluding BAC)	1.21	1.75	2.15
Toxicology post mortem (excluding BAC)	1.07	1.47	1.95
Trace Evidence	0.17	0.27	0.36

While the data in Table 1 is informative, a more natural metric for interpretaiton is the inverse of this metric, COST/CASE. It is more convenient since the concept of average cost is more easily interpreted and compared by laboratory management within and across activities, by legislatures and other funding bodies, and by stakeholders, in general.

The average cost (COST/CASE) when mapped against the caseload should yield a U-shaped curve with the downward sloped portion of the U highlighing greater economies of scale as caseload increases while the upward-sloped portion shows diseconomies of scale as average cost begins to rise with a rising caseload. Observation of scatter plots of the data for each area of investigation using the 2015–2016 FORESIGHT data suggests this theoretical relationship (e.g., see Figure 3), but not a symmetric curve. The FORESIGHT data reveals that a large portion of laboratories come from jurisdictions with lower caseloads over the declining average cost portion of the efficient frontier. Estimates of the relationship between COST/CASE and caseload using (8.1) provide a good visual fit to the data around the perfect economies of scale (i.e.,

Table 2. Cost per case by investigative area.

Area of Investigation	25th percentile	Median	75th percentile
Blood Alcohol	$90	$123	$230
Crime Scene Investigation	$792	$3,984	$6,765
Digital evidence - Audio & Video	$1,567	$3,188	$5,851
DNA Casework	$943	$1,335	$1,926
DNA Database	$59	$74	$166
Document Examination	$2,213	$3,451	$6,441
Drugs - Controlled Substances	$226	$313	$424
Evidence Screening & Processing	$485	$1,178	$1,777
Explosives	$6,489	$11,940	$20,550
Fingerprints	$490	$692	$975
Fire analysis	$1,054	$1,853	$2,905
Firearms and Ballistics	$920	$1,755	$3,066
Forensic Pathology	$1,602	$2,010	$3,053
Gun Shot Residue (GSR)	$1,560	$2,307	$3,628
Marks and Impressions	$2,751	$6,243	$8,907
Serology/Biology	$810	$1,479	$2,315
Toxicology ante mortem (excluding BAC)	$465	$571	$825
Toxicology post mortem (excluding BAC)	$514	$678	$933
Trace Evidence	$2,802	$3,637	$5,836

Table 4. DNA casework efficient frontier values.

Caseload	DNA Casework Efficient Cost/ Case	Caseload	DNA Casework Efficient Cost/ Case	Caseload	DNA Casework Efficient Cost/ Case
100	$3,917	2,700	$1,277	8,750	$1,164
200	$3,094	2,800	$1,261	9,000	$1,191
300	$2,696	2,900	$1,246	9,250	$1,220
400	$2,444	3,000	$1,232	9,500	$1,251
500	$2,266	3,250	$1,199	9,750	$1,283
600	$2,129	3,500	$1,169	10,000	$1,317
700	$2,021	3,750	$1,142	10,250	$1,353
800	$1,931	4,000	$1,117	10,500	$1,391
900	$1,855	4,250	$1,094	10,750	$1,430
1,000	$1,790	4,500	$1,073	11,000	$1,471
1,100	$1,733	4,750	$1,053	11,250	$1,514
1,200	$1,682	5,000	$1,035	11,500	$1,559
1,300	$1,637	5,250	$1,018	11,750	$1,606
1,400	$1,596	5,500	$1,002	12,000	$1,654
1,500	$1,559	5,750	$987	12,250	$1,704
1,600	$1,525	6,000	$983	12,500	$1,756
1,700	$1,494	6,250	$991	12,750	$1,809
1,800	$1,465	6,500	$1,000	13,000	$1,865
1,900	$1,439	6,750	$1,011	13,250	$1,922
2,000	$1,414	7,000	$1,024	13,500	$1,981
2,100	$1,391	7,250	$1,039	13,750	$2,041
2,200	$1,369	7,500	$1,055	14,000	$2,104
2,300	$1,348	7,750	$1,074	14,250	$2,168
2,400	$1,329	8,000	$1,094	14,500	$2,234
2,500	$1,311	8,250	$1,115	14,750	$2,302
2,600	$1,293	8,500	$1,139	15,000	$2,371

the central portion of the curve), but show much greater deviation when the observations are compared to the estimated relationship at the more extreme caseloads (low and high caseloads). Expressions (9.1) and (10.1), on the other hand, offer much tighter fits to the low and high caseload levels.

Further inspection of the shape of the scatter plot suggests that the lowest caseload portions of the average cost curve are associated with relatively steep curves, but then average cost declines at a declining rate. After bottoming out at perfect economies of scale, the diseconomies enter much more gradually; that is, the upward-sloped portion of the U-shape is much less steep than the downward portion. It appears that greater economies of scale follow a pattern different from the disconomies of scale. This implies that (8.1), (9.1), or (10.1) alone might not define the entire relationship.

Since *a priori*, we do not know the caseload associated with perfect economies of scale, a procedure was followed to let the data inform of the relationship. This is demonstrated for DNA Casework. First, each of the relationships (8.1), (9.1), and (10.1) were estimated over the entire range of submissions for the laboratories reporting DNA Casework for FORESIGHT 2015–2016. The sum of squared deviations were collected for each procedure. Subsequently, the N laboratories were split into two groups, (1, … , x) and (x+1, … , N) for x = 10 through x = N-10 and separate estimations were conducted using (8.1), (9.1), and (10.1) for each subset of the data and the corresponding sum of squared deviations was recorded for each possible paired estimation. The resulting U-shaped "possible efficient frontier" with the lowest sum of squared deviations was selected as the estimated efficient frontier. For DNA Casework, the selected specifications are highlighted in Table 3.

One hundred twenty-three of the FORESIGHT laboratories conducted DNA casework analysis. Table 3 provides the estimation of the efficient frontier for

Table 3. DNA casework estimated efficient frontier equations.

Dependent Variable	Obs.	Constant	Cases	$Cases^2$	LN (Cases)	F-statistic
Cost/Case	55	1,330.9474 (355.6750)	−0.1428 (0.1150)	1.41E-05 (7.78E-06)		5.5982
LN(Cost/Case)	64	9.8396 (0.3611)			−0.3402 (0.0532)	40.8246

DNA casework. (Note that similar estimations for 15 other areas of investigation are presented in tables located in the Appendix.) The specifications of Equations (8.1), (9.1), and (10.1) that minimized the squared deviations called for the double logarithmic form of Equation (10.1) for the first portion of the efficient frontier and the quadratic for Equation (8.1) the later portion of the frontier.

While the Table 3 estimates are informative, a conversion to the values of the COST/CASE for various caseloads may be more convenient for laboratory use. Table 4 offers the output with some smoothing conducted to connect the two estimate curves from Table 3.[2]

The use of Table 4 (and the related Appendix tables) is relatively straightforward. Suppose, for example, that a laboratory analyzes 700 DNA cases per year at an average cost of $2,000. While Table 2 suggests that this laboratory's average cost approaches the 75th percentile, relative to its caseload, Table 4 indicates that it is performing efficiently; the expected average cost per case for a laboratory with a 700 caseload in DNA Casework is $2,021. Expectations that the laboratory might lower its average cost without a corresponding increase in caseload are unrealistic. Process improvement programs are not the answer. The laboratory is already efficient. It can only expect to be more cost effective if higher volume occurs through another means, such as insourcing or an undesireable higher crime rate that increases the demand for the laboratory's services.

Using either Table 3 or Table 4, a laboratory may substitue its own caseload into the estimated equations from Table 3 or merely referencing their caseload and the efficient average cost from Table 4; the result suggests the efficient level of cost per case for comparison to the laboratory's current position to see potential gains from strategic initiatives.

Conclusions

The process improvement program undertaken by the NFI offers a great example of what might be accomplished through the implementation of best practices in management. This article observations and analysis to complement the presentations on the NFI efforts through insights into the economic foundations that provide direction into the forecasting of results from such process improvement (van Asten 2014; Tjin-A-Tsoi 2013). Before adopting similar change processes, forensic laboratory management should first assess the current position of productivity with respect to the efficient frontier, given the laboratory caseload in each area of investigation. Estimates of the efficient frontier are contained in the body of the paper for DNA casework and for other areas of investigation in the Appendix. Comparison to the efficient frontier, either for the output maximization problem or the cost minimization problem, enables management to assess whether an efficiency gap exists and if so, the size of the gap.

Once the size of the gap has been determined with respect to average cost, management can estimate the savings that might be achieved from a process improvement program. That process improvement will be accompanied by a reduction in TAT, which in turn influences the demand for services. Using this information and past experience, the laboratory can anticipate the increase in demand for services as a reaction to its improved productivity. Assessing the future average cost from the efficient frontier, management can then undertake the cost-benefit analysis to determine the worth of the process improvement program.

Notes

1. Office of Justice Programs (2016) suggests that for one area of investigation, DNA Casework, the queuing elasticity of demand falls into the elastic range with a value below -1. That suggests that process improvement efforts that reduce TAT will result in an increase in demand for DNA Casework (i.e., greater submissions) at a higher rate than the reduction in TAT.
2. The smoothing is merely an extension of each of the estimated curves through the overlap.

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Appendix

The estimation of Equations (8.1), (9.1), and (10.1) was conducted for each area investigation for which sufficient data was available from FORESIGHT 2015–2016. Following the same procedure as described for DNA Casework, Table 5 summarizes the estimations yielding the lowest combined squared deviations for each area of investigation. As with the analysis of DNA casework, a conversion of the equations was conducted to provide the estimated efficient cost per case for various caseloads. Table 6 offers the efficient frontier values for average cost per case across areas of investigation.

Table 5. Efficient frontier equations across areas of investigation.

Area of Investigation	Dependent Variable	Obs.	Constant	Cases	$Cases^2$	LN (Cases)	F-statistic
Blood Alcohol Analysis	LN(Cost/Case)	95	8.0769 (0.3689)			−0.3730 (0.0446)	69.8472
Crime Scene Investigation	LN(Cost/Case)	37	10.6801 (0.5574)			−0.5080 (0.0895)	32.2088
DNA Casework	Cost/Case	55	1,330.9474 (355.6750)	−0.1428 (0.1150)	1.41E-05 (7.78E-06)		5.5982
	LN(Cost/Case)	64	9.8396 (0.3611)			−0.3402 (0.0532)	40.8246
DNA Database	LN(Cost/Case)	51	9.8857 (0.3531)			−0.5833 (0.0393)	220.4712
Document Examination	Cost/Case	67	11,700.4971 (2,219.4849)			−1,467.53 (1,467.5261)	10.6132
Drugs–Controlled Substances	LN(Cost/Case)	95	7.7252 (0.3161)			−0.2268 (0.0364)	38.9251
Explosives Analysis	LN(Cost/Case)	56	9.8518 (0.2138)	−0.0171 (0.0070)			5.9797
Fingerprint Identification	Cost/Case	50	1,039.8871 (96.9909)	−0.1558 (0.0366)	7.62E-06 (2.16E-06)		13.1753
	LN(Cost/Case)	37	8.5142 (0.5424)			−0.2575 (0.0826)	9.7032
Fire Analysis	Cost/Case	43	10,939.9131 (1754.2301)	−51.0417 (10.06457)	6.36E-01 (0.0133)		13.7590
	LN(Cost/Case)	46	9.3391 (0.4726)			−0.3762 (0.1173)	10.2914
Firearms & Ballistics Analysis	LN(Cost/Case)	82	10.5126 (0.22546)			−0.4604 (0.0331)	193.9070
Gunshot Residue Analysis	Cost/Case	50	3,499.0378 (311.6808)	−7.9045 (1.9200)	6.40E-03 (0.0020)		11.7603
	LN(Cost/Case)	20	9.5960 (0.2189)			−0.3847 (0.0609)	39.9181
Marks & Impressions Analysis	LN(Cost/Case)	82	10.3337 (0.2977)			−0.5236 (0.0821)	40.6461
Serology/Biology Analysis	Cost/Case	14	1,644.8695 (122.7290)	−0.2699 (0.0734)	1.98E-05 (6.76E-06)		7.6499
	LN(Cost/Case)	80	11.5176 (0.6488)			−0.7079 (0.1261)	31.5317
Toxicology ante mortem Analysis	Cost/Case	50	778.9624 (78.5504)	−0.0841 (0.02666)	5.48E-06 (1.97E-06)		5.3116
	LN(Cost/Case)	20	11.0139 (1.0015)			−0.5989 (0.1477)	16.4359
Toxicology post mortem Analysis	LN(Cost/Case)	57	9.2721 (0.2526)			−0.3667 (0.03475)	111.8461
Trace Evidence Analysis	Cost/Case	70	5,305.6021 (338.3597)	−9.1043 (1.6713)	0.0064 (0.0015)		16.5600
	LN(Cost/Case)	25	10.6627 (0.3439)			−0.4954 (0.10224)	23.5105

Note: Standard errors are shown in parentheses

Table 6. Efficient frontier values for average cost per case across areas of investigation.

Caseload	Blood Alcohol Analysis Efficient Cost/Case	Caseload	Blood Alcohol Analysis Efficient Cost/Case	Caseload	Blood Alcohol Analysis Efficient Cost/Case
100	$578	6,500	$122	19,500	$81
200	$446	7,000	$119	20,000	$80
300	$384	7,500	$115	20,500	$79
400	$345	8,000	$113	21,000	$79
500	$317	8,500	$110	21,500	$78
600	$296	9,000	$108	22,000	$77
700	$280	9,500	$106	22,500	$77
800	$266	10,000	$104	23,000	$76
900	$255	10,500	$102	23,500	$75
1,000	$245	11,000	$100	24,000	$75
1,250	$225	11,500	$98	24,500	$74
1,500	$210	12,000	$97	25,000	$74
1,750	$199	12,500	$95	25,500	$73
2,000	$189	13,000	$94	26,000	$73
2,250	$181	13,500	$93	26,500	$72
2,500	$174	14,000	$92	27,000	$72
2,750	$168	14,500	$90	27,500	$71
3,000	$163	15,000	$89	28,000	$71
3,250	$158	15,500	$88	28,500	$70
3,500	$153	16,000	$87	29,000	$70
3,750	$150	16,500	$86	29,500	$69
4,000	$146	17,000	$85	30,000	$69
4,500	$140	17,500	$84	30,500	$68
5,000	$134	18,000	$83	31,000	$68
5,500	$130	18,500	$82	31,500	$68
6,000	$126	19,000	$82	32,000	$67
Caseload	**CSI Efficient Cost/Case**	**Caseload**	**CSI Efficient Cost/Case**	**Caseload**	**CSI Efficient Cost/Case**
5	$19,197	600	$1,687	3,200	$721
10	$13,500	700	$1,560	3,300	$710
15	$10,987	800	$1,457	3,400	$699
20	$9,493	900	$1,373	3,500	$689
25	$8,476	1,000	$1,301	3,600	$679
30	$7,726	1,100	$1,240	3,700	$670
40	$6,676	1,200	$1,186	3,800	$660
50	$5,960	1,300	$1,139	3,900	$652
60	$5,433	1,400	$1,097	4,000	$644
70	$5,024	1,500	$1,059	4,100	$635
80	$4,694	1,600	$1,025	4,200	$628
90	$4,422	1,700	$994	4,300	$620
100	$4,191	1,800	$965	4,400	$613
125	$3,742	1,900	$939	4,500	$606
150	$3,411	2,000	$915	4,600	$599
175	$3,154	2,100	$893	4,700	$593
200	$2,947	2,200	$872	4,800	$587
225	$2,776	2,300	$852	4,900	$580
250	$2,632	2,400	$834	5,000	$575
275	$2,507	2,500	$817	5,250	$560
300	$2,399	2,600	$801	5,500	$547
325	$2,303	2,700	$786	5,750	$535
350	$2,218	2,800	$771	6,000	$524
375	$2,142	2,900	$758	6,250	$513
400	$2,073	3,000	$745	6,500	$503
500	$1,851	3,100	$732	6,750	$493
Caseload	**DNA Casework Efficient Cost/Case**	**Caseload**	**DNA Casework Efficient Cost/Case**	**Caseload**	**DNA Casework Efficient Cost/Case**
100	$3,917	2,700	$1,277	8,750	$1,164
200	$3,094	2,800	$1,261	9,000	$1,191
300	$2,696	2,900	$1,246	9,250	$1,220
400	$2,444	3,000	$1,232	9,500	$1,251
500	$2,266	3,250	$1,199	9,750	$1,283
600	$2,129	3,500	$1,169	10,000	$1,317
700	$2,021	3,750	$1,142	10,250	$1,353
800	$1,931	4,000	$1,117	10,500	$1,391
900	$1,855	4,250	$1,094	10,750	$1,430
1,000	$1,790	4,500	$1,073	11,000	$1,471
1,100	$1,733	4,750	$1,053	11,250	$1,514

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Caseload	DNA Casework Efficient Cost/Case	Caseload	DNA Casework Efficient Cost/Case	Caseload	DNA Casework Efficient Cost/Case
1,200	$1,682	5,000	$1,035	11,500	$1,559
1,300	$1,637	5,250	$1,018	11,750	$1,606
1,400	$1,596	5,500	$1,002	12,000	$1,654
1,500	$1,559	5,750	$987	12,250	$1,704
1,600	$1,525	6,000	$983	12,500	$1,756
1,700	$1,494	6,250	$991	12,750	$1,809
1,800	$1,465	6,500	$1,000	13,000	$1,865
1,900	$1,439	6,750	$1,011	13,250	$1,922
2,000	$1,414	7,000	$1,024	13,500	$1,981
2,100	$1,391	7,250	$1,039	13,750	$2,041
2,200	$1,369	7,500	$1,055	14,000	$2,104
2,300	$1,348	7,750	$1,074	14,250	$2,168
2,400	$1,329	8,000	$1,094	14,500	$2,234
2,500	$1,311	8,250	$1,115	14,750	$2,302
2,600	$1,293	8,500	$1,139	15,000	$2,371
Caseload	DNA Database Efficient Cost/Case	Caseload	DNA Database Efficient Cost/Case	Caseload	DNA Database Efficient Cost/Case
100	$1,339	18,000	$65	44,000	$38
200	$894	19,000	$63	45,000	$38
300	$705	20,000	$61	46,000	$37
400	$596	21,000	$59	47,000	$37
500	$524	22,000	$58	48,000	$37
600	$471	23,000	$56	49,000	$36
700	$430	24,000	$55	50,000	$36
800	$398	25,000	$53	51,000	$35
900	$372	26,000	$52	52,000	$35
1,000	$350	27,000	$51	53,000	$34
2,000	$233	28,000	$50	54,000	$34
3,000	$184	29,000	$49	55,000	$34
4,000	$156	30,000	$48	56,000	$33
5,000	$137	31,000	$47	57,000	$33
6,000	$123	32,000	$46	58,000	$33
7,000	$112	33,000	$45	59,000	$32
8,000	$104	34,000	$45	60,000	$32
9,000	$97	35,000	$44	61,000	$32
10,000	$91	36,000	$43	62,000	$31
11,000	$86	37,000	$43	63,000	$31
12,000	$82	38,000	$42	64,000	$31
13,000	$78	39,000	$41	65,000	$31
14,000	$75	40,000	$41	66,000	$30
15,000	$72	41,000	$40	67,000	$30
16,000	$69	42,000	$40	68,000	$30
17,000	$67	43,000	$39	69,000	$30
Caseload	Document Examination Efficient Cost/Case	Caseload	Document Examination Efficient Cost/Case	Caseload	Document Examination Efficient Cost/Case
5	$9,339	170	$4,164	430	$2,802
10	$8,321	180	$4,080	440	$2,768
15	$7,726	190	$4,000	450	$2,735
20	$7,304	200	$3,925	460	$2,703
25	$6,977	210	$3,853	470	$2,671
30	$6,709	220	$3,785	480	$2,640
35	$6,483	230	$3,720	490	$2,610
40	$6,287	240	$3,658	500	$2,580
45	$6,114	250	$3,598	510	$2,551
50	$5,960	260	$3,540	520	$2,523
55	$5,820	270	$3,485	530	$2,495
60	$5,692	280	$3,431	540	$2,467
65	$5,574	290	$3,380	550	$2,441
70	$5,466	300	$3,330	560	$2,414
75	$5,364	310	$3,282	570	$2,388
80	$5,270	320	$3,235	580	$2,363
85	$5,181	330	$3,190	590	$2,338
90	$5,097	340	$3,146	600	$2,313
95	$5,018	350	$3,104	610	$2,289
100	$4,942	360	$3,062	620	$2,265
110	$4,802	370	$3,022	630	$2,241

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Caseload	Document Examination Efficient Cost/Case	Caseload	Document Examination Efficient Cost/Case	Caseload	Document Examination Efficient Cost/Case
120	$4,675	380	$2,983	640	$2,218
130	$4,557	390	$2,945	650	$2,195
140	$4,449	400	$2,908	660	$2,173
150	$4,347	410	$2,872	670	$2,151
160	$4,253	420	$2,836	680	$2,129
Caseload	Drugs-Controlled Substances Analysis Efficient Cost/Case	Caseload	Drugs-Controlled Substances Analysis Efficient Cost/Case	Caseload	Drugs-Controlled Substances Analysis Efficient Cost/Case
100	$797	11,000	$274	37,000	$208
200	$681	12,000	$269	38,000	$207
300	$621	13,000	$264	39,000	$206
400	$582	14,000	$260	40,000	$205
500	$553	15,000	$256	41,000	$204
600	$531	16,000	$252	42,000	$203
700	$513	17,000	$249	43,000	$201
800	$497	18,000	$245	44,000	$200
900	$484	19,000	$242	45,000	$199
1,000	$473	20,000	$240	46,000	$198
1,500	$431	21,000	$237	47,000	$197
2,000	$404	22,000	$235	48,000	$197
2,500	$384	23,000	$232	49,000	$196
3,000	$369	24,000	$230	50,000	$195
3,500	$356	25,000	$228	51,000	$194
4,000	$345	26,000	$226	52,000	$193
4,500	$336	27,000	$224	53,000	$192
5,000	$328	28,000	$222	54,000	$191
5,500	$321	29,000	$220	55,000	$191
6,000	$315	30,000	$219	56,000	$190
6,500	$309	31,000	$217	57,000	$189
7,000	$304	32,000	$215	58,000	$188
7,500	$299	33,000	$214	59,000	$188
8,000	$295	34,000	$212	60,000	$187
9,000	$287	35,000	$211	61,000	$186
10,000	$280	36,000	$210	62,000	$185
Caseload	Explosives Analysis Efficient Cost/Case	Caseload	Explosives Analysis Efficient Cost/Case	Caseload	Explosives Analysis Efficient Cost/Case
2	$18,352	28	$11,752	54	$7,525
3	$18,040	29	$11,552	55	$7,397
4	$17,733	30	$11,355	56	$7,271
5	$17,432	31	$11,162	57	$7,148
6	$17,136	32	$10,973	58	$7,026
7	$16,844	33	$10,786	59	$6,907
8	$16,558	34	$10,603	60	$6,789
9	$16,277	35	$10,423	61	$6,674
10	$16,000	36	$10,245	62	$6,561
11	$15,728	37	$10,071	63	$6,449
12	$15,461	38	$9,900	64	$6,339
13	$15,198	39	$9,732	65	$6,232
14	$14,939	40	$9,566	66	$6,126
15	$14,685	41	$9,404	67	$6,022
16	$14,436	42	$9,244	68	$5,919
17	$14,190	43	$9,087	69	$5,819
18	$13,949	44	$8,932	70	$5,720
19	$13,712	45	$8,781	72	$5,527
20	$13,479	46	$8,631	74	$5,341
21	$13,250	47	$8,485	76	$5,161
22	$13,025	48	$8,340	78	$4,987
23	$12,803	49	$8,199	80	$4,819
24	$12,586	50	$8,059	82	$4,656
25	$12,372	51	$7,922	84	$4,499
26	$12,161	52	$7,788	86	$4,348
27	$11,955	53	$7,655	88	$4,201
Caseload	Fingerprint Identification Efficient Cost/Case	Caseload	Fingerprint Identification Efficient Cost/Case	Caseload	Fingerprint Identification Efficient Cost/Case
100	$1,523	1,700	$797	7,750	$290
125	$1,438	1,800	$784	8,000	$281

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Caseload	Fingerprint Identification Efficient Cost/Case	Caseload	Fingerprint Identification Efficient Cost/Case	Caseload	Fingerprint Identification Efficient Cost/Case
150	$1,372	1,900	$771	8,250	$273
175	$1,319	2,000	$759	8,500	$266
200	$1,274	2,250	$728	8,750	$260
225	$1,236	2,500	$698	9,000	$255
250	$1,203	2,750	$669	9,250	$251
275	$1,174	3,000	$641	9,500	$248
300	$1,148	3,250	$614	9,750	$245
350	$1,103	3,500	$588	10,000	$244
400	$1,066	3,750	$563	10,250	$244
450	$1,034	4,000	$539	10,500	$244
500	$1,006	4,250	$515	10,750	$246
550	$982	4,500	$493	11,000	$248
600	$960	4,750	$472	11,500	$256
650	$941	5,000	$451	12,000	$268
700	$923	5,250	$432	12,500	$283
800	$920	5,500	$414	13,000	$303
900	$906	5,750	$396	13,500	$326
1,000	$892	6,000	$379	14,000	$353
1,100	$878	6,250	$364	14,500	$383
1,200	$864	6,500	$349	15,000	$418
1,300	$850	6,750	$336	15,500	$456
1,400	$837	7,000	$323	16,000	$498
1,500	$823	7,250	$311	16,500	$544
1,600	$810	7,500	$300	17,000	$594

Caseload	Fire Analysis Efficient Cost/Case	Caseload	Fire Analysis Efficient Cost/Case	Caseload	Fire Analysis Efficient Cost/Case
10	$4,784	140	$1,773	390	$702
15	$4,107	145	$1,749	400	$694
20	$3,686	150	$1,727	410	$699
25	$3,389	160	$1,686	420	$716
30	$3,164	170	$1,648	430	$746
35	$2,986	180	$1,613	440	$788
40	$2,840	190	$1,580	450	$844
45	$2,717	200	$1,550	460	$912
50	$2,611	210	$1,522	470	$993
55	$2,519	220	$1,495	480	$1,086
60	$2,438	230	$1,471	490	$1,192
65	$2,366	240	$1,447	500	$1,311
70	$2,301	250	$1,425	510	$1,443
75	$2,242	260	$1,404	520	$1,587
80	$2,188	270	$1,385	530	$1,744
85	$2,139	280	$1,366	540	$1,914
90	$2,093	290	$1,348	550	$2,096
95	$2,051	300	$1,331	560	$2,292
100	$2,012	310	$1,226	570	$2,500
105	$1,975	320	$1,116	580	$2,720
110	$1,941	330	$1,019	590	$2,953
115	$1,909	340	$934	600	$3,200
120	$1,878	350	$862	610	$3,458
125	$1,850	360	$803	620	$3,730
130	$1,823	370	$757	630	$4,014
135	$1,797	380	$723	640	$4,311

Caseload	Firearms & Ballistics Analysis Efficient Cost/Case	Caseload	Firearms & Ballistics Analysis Efficient Cost/Case	Caseload	Firearms & Ballistics Analysis Efficient Cost/Case
10	$12,740	550	$2,013	1,850	$1,152
20	$9,259	600	$1,934	1,900	$1,138
30	$7,682	650	$1,864	1,950	$1,124
40	$6,729	700	$1,802	2,000	$1,111
50	$6,072	750	$1,745	2,100	$1,086
60	$5,583	800	$1,694	2,200	$1,063
70	$5,201	850	$1,648	2,300	$1,042
80	$4,891	900	$1,605	2,400	$1,022
90	$4,633	950	$1,565	2,500	$1,003
100	$4,413	1,000	$1,529	2,600	$985
125	$3,982	1,050	$1,495	2,700	$968
150	$3,662	1,100	$1,463	2,800	$952

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Caseload	Firearms & Ballistics Analysis Efficient Cost/Case	Caseload	Firearms & Ballistics Analysis Efficient Cost/Case	Caseload	Firearms & Ballistics Analysis Efficient Cost/Case
175	$3,411	1,150	$1,434	2,900	$936
200	$3,207	1,200	$1,406	3,000	$922
225	$3,038	1,250	$1,380	3,250	$889
250	$2,894	1,300	$1,355	3,500	$859
275	$2,770	1,350	$1,332	3,750	$832
300	$2,661	1,400	$1,309	4,000	$808
325	$2,565	1,450	$1,288	4,250	$785
350	$2,479	1,500	$1,268	4,500	$765
375	$2,401	1,550	$1,249	4,750	$746
400	$2,331	1,600	$1,231	5,000	$729
425	$2,267	1,650	$1,214	5,250	$713
450	$2,208	1,700	$1,197	5,500	$697
475	$2,154	1,750	$1,182	5,750	$683
500	$2,104	1,800	$1,166	6,000	$670

Caseload	Gunshot Residue Efficient Cost/Case	Caseload	Gunshot Residue Efficient Cost/Case	Caseload	Gunshot Residue Efficient Cost/Case
2	$11,264	110	$2,707	475	$1,198
4	$8,628	120	$2,643	500	$1,157
6	$7,382	130	$2,580	525	$1,125
8	$6,609	140	$2,519	550	$1,100
10	$6,065	150	$2,458	575	$1,084
12	$5,654	160	$2,399	600	$1,075
14	$5,329	170	$2,341	625	$1,075
16	$5,062	180	$2,285	650	$1,083
18	$4,838	190	$2,230	675	$1,099
20	$4,646	200	$2,176	700	$1,122
25	$4,264	210	$2,123	725	$1,154
30	$3,975	220	$2,072	750	$1,194
35	$3,746	230	$2,022	775	$1,242
40	$3,558	240	$1,973	800	$1,298
45	$3,401	250	$1,926	825	$1,362
50	$3,266	260	$1,879	850	$1,434
55	$3,148	270	$1,834	875	$1,515
60	$3,048	280	$1,791	900	$1,603
65	$3,012	290	$1,748	925	$1,699
70	$2,977	300	$1,707	950	$1,804
75	$2,942	325	$1,610	975	$1,916
80	$2,908	350	$1,522	1,000	$2,036
85	$2,874	375	$1,441	1,025	$2,165
90	$2,840	400	$1,368	1,050	$2,301
95	$2,806	425	$1,303	1,075	$2,446
100	$2,773	450	$1,246	1,100	$2,599

Caseload	Marks & Impressions Efficient Cost/Case	Caseload	Marks & Impressions Efficient Cost/Case	Caseload	Marks & Impressions Efficient Cost/Case
3	$17,300	81	$3,080	260	$1,672
6	$12,035	84	$3,022	270	$1,640
9	$9,733	87	$2,967	280	$1,609
12	$8,372	90	$2,915	290	$1,580
15	$7,448	95	$2,833	300	$1,552
18	$6,770	100	$2,758	310	$1,525
21	$6,245	105	$2,689	320	$1,500
24	$5,823	110	$2,624	330	$1,476
27	$5,475	115	$2,564	340	$1,453
30	$5,181	120	$2,507	350	$1,431
33	$4,929	125	$2,454	360	$1,410
36	$4,710	130	$2,404	370	$1,390
39	$4,516	135	$2,357	380	$1,371
42	$4,344	140	$2,313	390	$1,353
45	$4,190	145	$2,271	400	$1,335
48	$4,051	150	$2,231	410	$1,318
51	$3,924	160	$2,157	420	$1,301
54	$3,809	170	$2,089	430	$1,285
57	$3,702	180	$2,028	440	$1,270
60	$3,604	190	$1,971	450	$1,255
63	$3,513	200	$1,919	475	$1,220
66	$3,429	210	$1,870	500	$1,188

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Caseload	Marks & Impressions Efficient Cost/Case	Caseload	Marks & Impressions Efficient Cost/Case	Caseload	Marks & Impressions Efficient Cost/Case
69	$3,350	220	$1,825	525	$1,158
72	$3,276	230	$1,783	550	$1,130
75	$3,207	240	$1,744	575	$1,104
78	$3,142	250	$1,707	600	$1,079

Caseload	Serology/ Biology Efficient Cost/Case	Caseload	Serology/ Biology Efficient Cost/Case	Caseload	Serology/ Biology Efficient Cost/Case
10	$19,683	375	$1,546	3,300	$970
20	$12,050	400	$1,540	3,550	$937
30	$9,043	425	$1,534	3,800	$905
40	$7,377	450	$1,527	4,050	$877
50	$6,299	475	$1,521	4,300	$851
60	$5,536	500	$1,515	4,550	$827
70	$4,964	550	$1,502	4,800	$806
80	$4,516	600	$1,490	5,050	$787
90	$4,155	650	$1,478	5,300	$771
100	$3,856	700	$1,466	5,550	$757
110	$3,605	800	$1,442	5,800	$746
120	$3,389	900	$1,418	6,050	$737
130	$3,203	1,000	$1,395	6,550	$727
140	$3,039	1,100	$1,372	7,050	$727
150	$2,894	1,200	$1,350	7,550	$737
160	$2,765	1,300	$1,328	8,050	$757
170	$2,649	1,400	$1,306	8,550	$786
180	$2,544	1,500	$1,285	9,050	$826
190	$2,448	1,600	$1,264	9,550	$875
200	$2,361	1,700	$1,243	10,050	$934
225	$2,172	1,800	$1,223	10,550	$1,004
250	$2,016	2,050	$1,175	11,050	$1,083
275	$1,884	2,300	$1,129	11,550	$1,172
300	$1,772	2,550	$1,086	12,050	$1,271
325	$1,674	2,800	$1,045	13,050	$1,498
350	$1,589	3,050	$1,006	14,050	$1,765

Caseload	Toxicology ante mortem Efficient Cost/Case	Caseload	Toxicology ante mortem Efficient Cost/Case	Caseload	Toxicology ante mortem Efficient Cost/Case
300	$1,994	2,900	$581	6,250	$468
400	$1,678	3,000	$576	6,500	$464
500	$1,468	3,100	$571	6,750	$461
600	$1,316	3,200	$566	7,000	$459
700	$1,200	3,300	$561	7,250	$458
800	$1,108	3,400	$556	7,500	$457
900	$1,032	3,500	$552	7,750	$457
1,000	$969	3,600	$547	8,000	$457
1,100	$916	3,700	$543	8,250	$458
1,200	$869	3,800	$539	8,500	$460
1,300	$828	3,900	$534	8,750	$463
1,400	$792	4,000	$530	9,000	$466
1,500	$760	4,100	$526	9,250	$470
1,600	$732	4,200	$523	9,500	$475
1,700	$705	4,300	$519	9,750	$480
1,800	$682	4,400	$515	10,000	$486
1,900	$660	4,500	$512	10,250	$493
2,000	$640	4,600	$508	10,500	$500
2,100	$627	4,700	$505	10,750	$509
2,200	$621	4,800	$502	11,000	$517
2,300	$615	4,900	$499	11,500	$537
2,400	$609	5,000	$496	12,000	$559
2,500	$603	5,250	$489	12,500	$584
2,600	$597	5,500	$482	13,000	$612
2,700	$592	5,750	$477	13,500	$643
2,800	$587	6,000	$472	14,000	$676

Caseload	Toxicology ante mortem Efficient Cost/Case	Caseload	Toxicology ante mortem Efficient Cost/Case	Caseload	Toxicology ante mortem Efficient Cost/Case
10	$4,573	950	$861	3,750	$520
20	$3,546	1,000	$845	4,000	$508
30	$3,057	1,050	$830	4,250	$497
40	$2,751	1,100	$816	4,500	$487

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Caseload	Toxicology ante mortem Efficient Cost/Case	Caseload	Toxicology ante mortem Efficient Cost/Case	Caseload	Toxicology ante mortem Efficient Cost/Case
50	$2,534	1,150	$803	4,750	$477
60	$2,371	1,200	$790	5,000	$468
70	$2,240	1,250	$779	5,250	$460
80	$2,133	1,300	$767	5,500	$452
90	$2,043	1,350	$757	5,750	$445
100	$1,966	1,400	$747	6,000	$438
150	$1,694	1,450	$737	6,250	$432
200	$1,525	1,500	$728	6,500	$425
250	$1,405	1,600	$711	6,750	$420
300	$1,314	1,700	$696	7,000	$414
350	$1,242	1,800	$681	7,250	$409
400	$1,182	1,900	$668	7,500	$404
450	$1,132	2,000	$655	8,000	$394
500	$1,089	2,100	$644	8,500	$386
550	$1,052	2,200	$633	9,000	$378
600	$1,019	2,300	$623	9,500	$370
650	$990	2,400	$613	10,000	$363
700	$963	2,500	$604	10,500	$357
750	$939	2,750	$583	11,000	$351
800	$917	3,000	$565	12,000	$340
850	$897	3,250	$548	13,000	$330
900	$878	3,500	$534	14,000	$321

Caseload	Trace Evidence Analysis Efficient Cost/Case	Caseload	Trace Evidence Analysis Efficient Cost/Case	Caseload	Trace Evidence Analysis Efficient Cost/Case
5	$19,253	135	$4,193	380	$2,766
10	$13,658	140	$4,156	390	$2,724
15	$11,173	145	$4,119	400	$2,683
20	$9,689	150	$4,083	410	$2,643
25	$8,675	160	$4,012	420	$2,605
30	$7,926	170	$3,942	430	$2,568
35	$7,343	180	$3,873	440	$2,533
40	$6,873	190	$3,806	450	$2,498
45	$6,484	200	$3,739	475	$2,418
50	$6,154	210	$3,675	500	$2,346
55	$5,870	220	$3,611	525	$2,281
60	$5,623	230	$3,549	550	$2,225
65	$5,404	240	$3,487	575	$2,176
70	$5,209	250	$3,428	600	$2,136
75	$5,034	260	$3,369	625	$2,103
80	$4,876	270	$3,312	650	$2,079
85	$4,732	280	$3,256	675	$2,062
90	$4,599	290	$3,201	725	$2,053
95	$4,498	300	$3,148	775	$2,075
100	$4,459	310	$3,095	825	$2,130
105	$4,420	320	$3,044	875	$2,216
110	$4,381	330	$2,995	925	$2,334
115	$4,343	340	$2,946	1,025	$2,665
120	$4,305	350	$2,899	1,125	$3,124
125	$4,267	360	$2,853	1,225	$3,710
130	$4,230	370	$2,809	1,325	$4,424