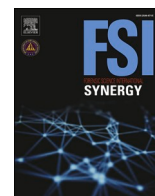


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The sentinel role of forensic toxicology laboratories to identify and act upon diverse drug threats by addressing toxicology and economic demands[☆]

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1. Introduction

Over the past decade, forensic toxicology laboratories have experienced an accelerated increase in the demand for toxicological analyses without a corresponding growth in resources. This growth in demand outweighs the growth in resources to meet those demands, resulting in consequences like an inevitable increase in turnaround times and increased backlog [1]. The increased demand for testing may be attributed to several sources, including deaths caused by the abuse of emerging drugs, heightened polypharmacy drug use patterns, or bottlenecks in services as some jurisdictions legalize the use of previously controlled substances [2–4]. For instance in 2016 and 2017, over 28,000 deaths were credited to the ingestion of synthetic opioids [5]. This incredible increase in overdoses has left forensic laboratories experiencing greater testing backlogs and ultimately less time to execute a proactive analytical response improving detection of emerging misused and abused substances. The societal costs from substance abuse are extensive and include treatment and healthcare costs, lost productivity, death, and costs to the justice system. These justice system costs include labor needs, analytical costs, and drug surveillance and preparedness among police, forensic laboratories and courts, and correctional facilities. Faster recognition of the drug landscape through analytical surveillance and intelligence and an anticipation of needed changes are required to better understand the economic implications of the demands of increased and novel toxicological testing that can provide a sentinel prediction of jurisdictional trends.

The 2019 Department of Justice Report to Congress on the status and needs of crime laboratories highlights the broad impact of the opioid crisis on limited public sector resources [6]. For these forensic laboratories, maintaining *status quo* workflow requires over 900 additional

positions. Jurisdictions have been slow to react with sufficient funding to keep up with the growing demands for laboratory services. As a result, turnaround times lengthen, and the backlog grows.

Traditionally, one thinks of drug use patterns as surveillance and intelligence to inform public health and safety, but economics, policy, and legislation trends are also important to consider. For example, there are lessons learned from the experience of diverse drug threats as jurisdictions contemplate changes to existing legislation for legalization,¹ enforcement, and punishment for cannabis as an illicit psychoactive substance [7]. The current trends of cannabis legalization provide some insight into future drug legalization as an alternative solution to combat crime, corruption, and violence associated with illicit drug markets [8]. Many believe the repeal of prohibitionist and recovery option policies can reduce stigma and remove addiction treatment barriers for those suffering from drug addiction. Debates around the legalization of cannabis for medical and/or recreational use have continued for decades [9–11]. However, benefits such as personal freedom and increased public revenues come with additional societal costs, among which are those arising from drug abuse such as the potential growth in substance use disorders [12]. As highlighted by a White House report [13], the opioid crisis has resulted in an annual societal cost that exceeds 2% of the U.S. gross domestic product.

States legalizing medical or recreational use of cannabis are markedly slow to realize the increased demands on forensic laboratories that follow. As other states consider passing legislation on the medical or recreational use of cannabis, they should plan for the increased demands on the forensic laboratory as an associated cost and should dedicate resources for testing. Illuminating the societal costs will assist in that planning. This issue also goes beyond the United States. The recent legalization of cannabis in Canada coupled with the growth in the

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¹ Legalization is the possession or use of a substance is legal with state imposed legislative requirements.

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Canadian opioid crisis has increased demands upon their forensic laboratories [1].

These diverse trends, along with the emergence of COVID-19, have intensified the crisis for forensic laboratories. Combinations of isolation, an individual's ready access to cash, and other social factors have been met with substantial growth in overdose deaths and additional demands upon the forensic laboratories, public health, and mental health treatment [14–18].

In the following sections, we examine the considerable amount of available literature and data supporting the toxicology and economic demands that contribute to the ever-increasing opportunity costs for forensic testing. Modeling data from the National Highway Traffic Safety Administration, insurance industry, and Project FORESIGHT [19], cost estimates are evaluated resulting from delays in processing DUID cases. We follow the technique to value a statistical life [20] to estimate the costs of delayed processing and compare the associated opportunity cost with the cost of additional staffing targeted towards alternative turnaround times in the laboratory. Together, these estimates provide benefit-to-cost ratios and return of investment metrics for policymakers.

2. Toxicology demands

There is a myriad of challenges that the forensic laboratory faces with ever-increasing toxicology demands. These diverse challenges include rapidly emerging and changing unknown substances in the drug market, legislation requirements (e.g., cannabis legalization, 2018 Farm Bill for hemp products, fentanyl analogs), analytical requirements, testing turnaround times, and training [2,21–24]; U.S. Congress, 2018).

Rapidly expanding unknown substances of abuse, characterized as emerging drug threats, require constant surveillance by forensic toxicologists [2]. These emerging substances continue to evolve and change, forcing identification and detection schemes to keep up or risk non-discovery [2,24]. These drug threats have driven forensic toxicologists to adopt new methods for detection and identification. The pervasiveness of poly drug use by individuals provides additional pressure on workloads [3]. Furthermore in the investigations of DUID, difficulty of creating a limit for cannabis due to how long it can stay in the body of a frequent user adds to the complexities of interpreting the limit of cannabis detected (i.e., is the drug detected due to regular use or due to this one time acute use from DUID) [25].

As a seemingly invisible participant in the justice system's efforts to deal with the changing drug landscape, the forensic laboratory has been inundated with casework related to evolving drug use from drug chemistry to toxicology [3]. Unfortunately, the resources to deal with this growing social problem have failed to materialize. However, could we have predicted these resource demands? Consider, for example, Washington State. The legalization of cannabis was expected to generate over \$300 million annually in tax revenues, which has come to fruition—but additional funds were not planned for the potential increase in forensic laboratory testing, and driving under the influence of drugs (DUID) toxicology cases have doubled to reach a backlog of over 6000 cases [26]. Although some emergency allocations to the laboratory occurred over the years, the permanent investment in staffing took several years to realize. In addition, the costs from DUID testing go well beyond cannabis use. A recent analysis of the rise in Phencyclidine (PCP) DUID cases in Houston, Texas, highlights the need to be vigilant in identifying increased trends for more traditional drugs and quickly reacting and providing needed laboratory funding [27,28].

Although toxicology has advanced over time, it has retained the notion that “the dose makes the poison,” and toxicologists must remain observant of this concept with the abuse of emergent drugs at an all-time high [2,24]. The continuous introduction of unknown misused substances complicates laboratory development of robust and validated methods and complex case interpretation are standards [29]. As laboratories continue to adapt to changes, these issues will persist, and

cost-benefit analysis will scrutinize options as limited resources persist.

3. The economic problem and rationing public budgets

Economically, there are limited resources available for unlimited needs for public budgets in the United States. Hence, some form of rationing must occur as a prioritization process to weigh the gains and losses from legislative actions. The marginal benefit to marginal cost ratio offers a simple comparative metric of the societal dollars received per dollar spent. Decision-makers can rank prospective projects across all opportunities that provide a benefit that exceeds the cost. Likewise, the ROI metric relates the net marginal benefits—that is, the additional benefits minus additional costs. The corresponding rates of return offer a rate comparison as objective support for the commitment of public funds.

We can provide some indication of the value added from a jurisdiction's investment into additional toxicologists to meet the increased demand for services from legalization of cannabis and the other demands for toxicological services [30]. Although a state may legalize cannabis possession and use, this decision can affect DUID occurrences and subsequently the need for forensic testing [31]. Determining both the additional costs and the additional benefits involves detailed investigation.

There are significant economies of scale associated with toxicological analysis [3,32]. First, consider the marginal costs associated with the addition of one toxicologist. Because forensic laboratories generally provide services restricted to their jurisdiction, marginal costs and marginal productivity of analysts vary greatly according to the caseload of the jurisdictions served. For example, a forensic laboratory analyzing 500 toxicology antemortem cases (e.g., DUID, clinical) per year faces a marginal cost of \$724 for an additional case whereas a laboratory handling 8000 cases only has a marginal cost of \$310 [33]. Although local salary and benefits will explain a part of the difference in costs, most of the explanation comes from the analyst productivity associated with greater economies of scale [33,34].

Second, measuring the benefits requires identifying costs saved from preventing harms. For DUID cases, measuring potential harms begins with the costs of crashes from property, injury, and death [35]. This requires an estimation of the likelihood of such crashes and the frequency of impaired driving. Other harms prevented include costs of physical and mental health treatment for the impairer. Beyond the societal costs from the impaired driver, there are benefits from exonerating innocent persons suspected of impaired driving. Unlike *per se* laws for alcohol impairment, few jurisdictions have defined measurable indicators of impairment. At the time of writing this publication, eighteen states have laws to indicate impairment with cannabis or cannabis (tetrahydrocannabinol, [THC] as the active ingredient and forensically tested substance): 12 states have a zero-tolerance law for THC, five states have specific *per se* limits, and one state has a permissible inference law of 5 ng/mL THC in blood infers impairment [30]. Instead, these jurisdictions rely upon the judgement of enforcement officials.

4. Project FORESIGHT and fully loaded costs

Cost data are available via Project FORESIGHT [1,19,33]. Project FORESIGHT collects data voluntarily provided by forensic laboratories worldwide and provides a cost picture of forensic analysis for various areas of investigation. The cost data represent fully loaded costs with detail on expenditures for capital, personnel, consumables, and overhead.

Project FORESIGHT collects data aligned with the mission of forensic laboratories to maximize quality case processing given the budgets at their disposal [36]. Maximizing cases processed relative to the budget is akin to minimizing the average cost of the quality-analyzed caseload in each area of forensic investigation.

Project analysts provide projections for various efficiency metrics,

such as the average total costs (ATC) and marginal costs (MC) for toxicology antemortem (DUID, clinical), depicted in Fig. 1. Fig. 1 visualizes the forecasted efficient frontier, showing the relationship between ATC, MC, and the concept of economies of scale (i.e., cost reductions that occur with increase in production/testing). Because capital expenditures on equipment are commonly made in consolidated purchases, matching hours of personnel use with fixed cost expenditures produces productivity gains. As a caseload increases, laboratories experience lower ATC and MC via greater economies of scale as depicted through the declining ATC curve. At a caseload of approximately 7325 annual cases, a laboratory achieves perfect economies of scale (i.e., ATC is minimized). For higher caseloads, a laboratory would experience diseconomies of scale, as reflected with MC exceeding the average total cost. The illustrated smooth curves represent the econometric estimate of the efficient frontier for Project FORESIGHT laboratories for fiscal year 2020 estimating the frontier relationship from the raw data points. This notion of efficiency estimates the declining ATC and MC that is possible as caseload increases through perfect economies of scale. For fiscal year 2020, over 95% of FORESIGHT reporting laboratories operated on the downward-sloped portion of the ATC curve (caseloads of 312–6930).

When ultimately combined with estimates of the societal benefits, the declining costs for most laboratories suggest that laboratories that can analyze a larger caseload will experience a greater benefit per dollar invested and a higher ROI. The benefit per dollar metric and the ROI expected will vary with the caseload within each jurisdiction.

Understanding the economies of scale associated with forensic analysis is critical to the funding decision for public sector laboratories. With declining costs, jurisdictions face a dynamic rather than a static problem. That is, the ROI will be a moving target with greater potential ROI as long as additional economies of scale are possible.

Most of those gains will be attributable to growth in productivity for personnel in the laboratory [34]. A workforce calculator tool enables the determination of exactly how many additional personnel the laboratory needs to handle any growth in caseload [37,38]. Fig. 2 illustrates the growth in personnel required to meet the demands from higher caseloads across a broad spectrum of jurisdictions [33]. Fig. 2 provides the estimate from efficient frontier number of full-time equivalent (FTE) staff across all possible caseloads as estimated fiscal year 2020 Project FORESIGHT data across all types of jurisdictions rather than input for a specific type of jurisdiction and a specific set of populations served by the jurisdiction. The FTE personnel grow at a decreasing rate. This reflects another economic law, the Law of Diminishing Marginal Returns. Fig. 3 captures the Law of Diminishing Marginal Returns because it shows the declining growth rate in productivity anticipated by laboratories as the caseload increases.

5. Benefits from toxicological analysis

Measurements of benefits come from measuring the avoidance of harms. This requires estimating the cost of harms and determining the probabilities of those harms occurring. Evaluating the benefits from enforcing DUID laws begins with an estimation of damage from the harms of vehicular crashes. Economic harms include crashes that result in property damage, injury, or fatalities. When the estimated cost from the various harms is connected with the probability of those harms associated with a given action, a societal expected cost results.

Studies across various developed countries provide a range of outcomes from which to project probabilities of DUID, likelihood of crashes occurring while under the influence, and the expected losses from crashes (e.g., Refs. [39,40]; iii.org, 2019; [41,42]). First, consider the number of vehicular crashes in the United States from all causes and the losses incurred from those crashes.

Table 1 offers a conservative estimate of the costs incurred from vehicular crashes. The U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA) data on the number of crashes across the United States are presented in the first data row in

Table 1 with a breakdown for crashes that resulted in fatalities, injury, or property damage only [43]. The next line provides a conservative estimate of the economic harm from cannabis-attributed vehicular crashes, which depends upon the extent of the harms considered [42].² The [42] harms data pertain to the estimated costs for vehicular crashes in Canada. Table 1 data were converted to U.S. dollars (USD) from Canadian dollars (<http://xe.com>) with updates to current dollars using the Consumer Price Index (in 2021 dollars; i.e., 2021 = 100).

We emphasize that these are “conservative estimates.” For example, the economic harm of \$9.98 million is less than the \$11.8 million economic harm for 2021 suggested by the U.S. Department of Transportation [44]. Likewise, the estimated economic harm of \$98,998 per injury accident is approximately half the cost of injury treatment in the United States compared with Canada [45]. Insurance industry coverage between Canada and the United States suggests similar cost structures for non-injury crashes, but no firm cost comparisons are available for property damage economic harms. Lacking a consistent measure of harms across all three categories, Table 1 presents this conservative estimate of harms.³ The total costs from harms for each vehicular crash type is a multiple of number of crashes and the economic harm per crash.

The estimation of harms by type of outcome follows a willingness-to-pay model with an estimate of the cost of harms from traffic crashes of \$584 billion annually.⁴ The next detail in Table 1 with the total direct costs of \$301 billion includes lost productivity and workplace costs, medical and health services costs, legal costs, insurance processing costs, and property damage [20,46]. Total social costs of \$1.04 trillion represent an alternative measure of the direct costs along with the loss in quality of life (i.e., quality-adjusted life years) related to the accident (Neumann et al., 2016).⁵ As Table 1 indicates, measures of the cost of harms depend upon the interpretation of the measure. The benefit to be used in the benefit-to-cost ratio or the ROI comes from the avoidance of that harm.

The likelihood of being able to prevent these harms depends on many factors, including the relative frequency that individuals drive under the influence of drugs, enforcement of DUID laws, and probability that law enforcement catches a DUID driver [43]. Using their Fatality Analysis Reporting System, NHTSA also reported that drug use among fatally injured drivers who were tested for drugs rose from 25% in 2007 to 42% in 2016. Cannabis presence more than doubled in this time frame from 8% to 18% [47,48]. The Government Accountability Office notes the lack of standardization for drug impairment and drug testing makes data collection and reporting unreliable. Although some *per se* laws exist, there is no general acceptance of the level of drug concentrations that denote impairment. Combined with the lack of reliable roadside testing, the delays to obtain blood samples for testing limits the options for determining the relative frequency of DUID to address the problem [49]. Because the negative performance effects such as impaired psychomotor skills, divided attention, lane tracking, and cognitive functions from cannabis are heightened in the first 10–30 min after use and then tend to dissipate to baseline within 3–5 h, current testing practices are unable to fully capture the extent of the abuse from DUID [25,50–52].

Some jurisdictions have learned from this problem in the United

² The [42] estimated costs from cannabis-attributed vehicular crashes represent a conservative estimate for vehicular deaths (U.S. Department of Transportation National Highway Traffic Safety Administration (2019)). It is unknown whether cannabis-attributed vehicular crashes resulting in injury or property damage differ in average costs.

³ The conservative estimate of fatality harms understates the cost of these harms by \$61 billion from the U.S. Department of Transportation 2021 estimate. The conservative estimate of economic harms from injury underestimates the cost by \$191 billion from Ref. [45].

⁴ WTP calculations (willingness to pay economic model) represent the market value or reservation price, a reflection of the demands for goods or services.

⁵ A QALY, a quality adjusted life year, is a health economics measure that attempts to correct for any loss of quality from an economic harm to health.

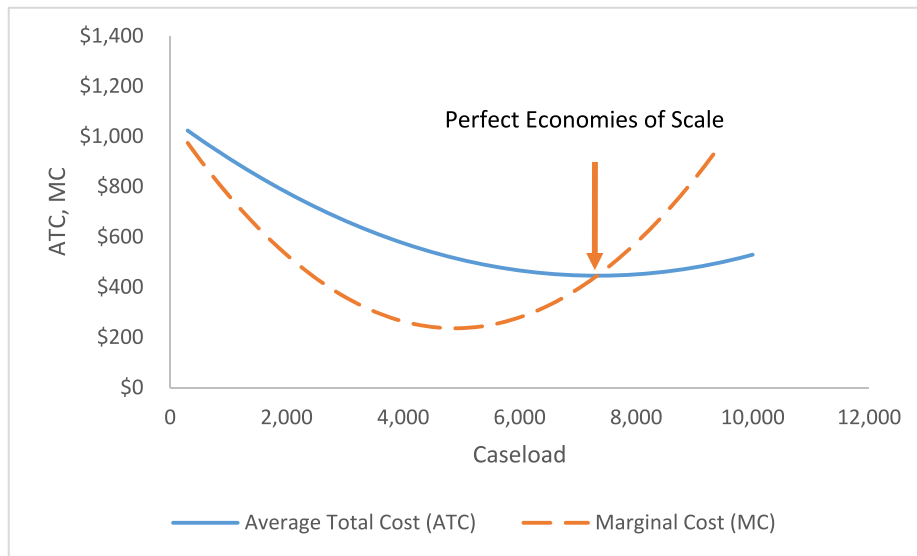


Fig. 1. The Average Total Costs (ATC) and Marginal Costs (MC) for Toxicology Antemortem (DUID, clinical) Efficiency Cost Curves in 2020. Source: Project FORESIGHT [33].

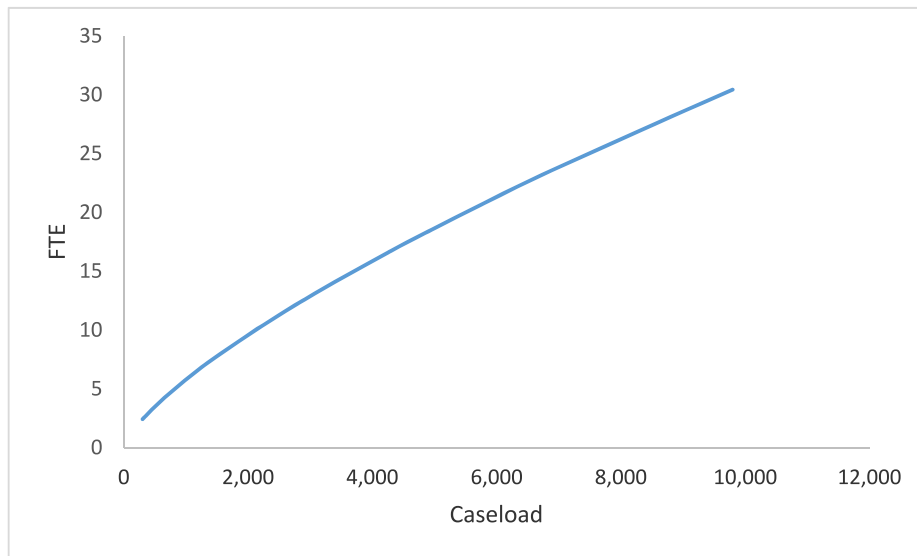


Fig. 2. Growth in Personnel (FTEs) Needed to Meet the Demands from Higher Toxicology Antemortem Testing Caseloads as Estimated for Fiscal year 2020. Source: Project FORESIGHT [33].

States and have included restrictions in their legalization efforts to overcome these limitations. Similarly, countries such as Canada included updates to its criminal code with *per se* limits for drivers for cannabis and eight other substances. The Canadian updates included roadside testing with the collection of oral fluid samples for drug screening, permitted blood samples to be drawn by qualified technicians, and stipulated mandatory alcohol screening [53].

Without reliably collected data, estimating the probabilities of DUID falls to self-reported survey data, data from other countries, and event studies surrounding the legalization of drugs [54]. In a French study, the rate of DUID from cannabis was estimated to be 3.4%, compared with 2.1% for the DUID rate for alcohol. The cannabis-impaired drivers increased their likelihood of involvement in a fatal accident by 1.65 times that of an unimpaired driver. The alcohol-impaired driver was 17.8 times more likely to be the cause of a fatality than the unimpaired driver [41].

The Insurance Information Institute reports on event studies related

to the legalization of cannabis. Their data indicate that when states legalize medical or recreational use of cannabis, there is 6% higher rate of collision claims than found in surrounding states. For Washington State, the number of drivers testing positive for cannabis doubled in the years following legalization (iii.org, 2019). Following the legalization of medical cannabis in Colorado, fatalities with drivers testing positive for cannabis increased, while there was no change in alcohol-related accident fatalities [55]. Self-reported surveys indicate that the rates of DUI from alcohol or drugs is growing. Surveys from 2007 to 2014 show a growth in DUI from alcohol or drugs has grown from 4.2% to 12.2% in the United States [40]. That period coincides with the legalization of cannabis for many U.S. states.

The benefits to be realized from eliminating harms grow with the level of enforcement of DUID laws. With greater enforcement programs, there will be greater arrests and convictions and more harms avoided. There is another impact from increases in arrests, particularly when the arrest includes the collection of DNA samples from arrestees for DUID.

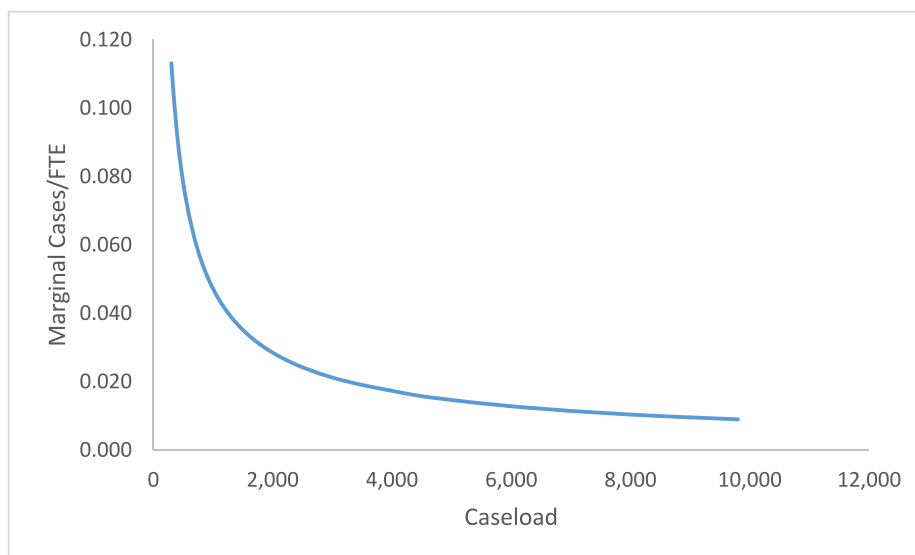


Fig. 3. The estimated declining growth rate (toxicology antemortem marginal Cases/FTE) in laboratory productivity with increased caseload. Source: Project FORESIGHT [33].

Table 1

Conservative cost estimates (economic harm, direct, societal represented by fatalities, injuries, and property damage resulting from) from vehicular crashes in the United States.

	Fatalities	Injury	Property Damage	Total from Crashes
Number of Crashes (2018)*	33,654	1,894,000	4,807,000	6,734,654
Economic Harm per Crash (USD, 2021 = 100)**	\$9,984,261	\$98,998	\$12,521	
Total Cost from Harms**	\$336,010,319,616	\$187,501,711,386	\$60,188,399,942	\$583,700,430,944
Total Direct Costs***				\$301,140,761,119
Total Social Costs***				\$1,040,304,447,501

Source: * [43], ** [42]; *** [39].

Merely collecting arrestee DNA serves as a deterrent. As jurisdictions expand DNA collection to include arrestees for entry into a DNA database, there is a corresponding reduction in crime of all sorts [56]. The potential for DNA associations with other crimes has a greater impact on the commission of crime than harsher punishment [57]. These impacts are greatest for violations by younger offenders as found with DUID with cannabis. Self-reported data indicate that young offenders have the highest percentages of drugged driving at 12.7% for the 21–25 age group and 9.4% for the 16–20 age group [58].

6. Predicting and reacting to trends in DUID

The experiences of U.S. states, such as Colorado and Washington, provide key planning information for other jurisdictions as they consider the legalization of cannabis for medical or recreational use [55,59,60]. Likewise, Ontario’s Centre for Forensic Science anticipated the growth in toxicology cases that would follow legalization of cannabis in Canada and increased the number of toxicologists in the laboratory by a dozen [1,33]. Such planned changes in law permit the anticipation of staffing needs.

However, other changes in drug trends that impact DUID cases may be more difficult to predict. This is particularly true of novel substances where slight modifications in the chemical makeup quickly replace other synthetics. There are societal savings to be gained from a more proactive response to emerging drugs and the forensic toxicology laboratory can play a key role in the prevention of harms. Proactive responses within research and casework forensic laboratories can include determining targeted metabolites early for analysis of novel psychoactive substances (NPS); making identified NPS, including synthetic cannabinoids, and their targeted metabolites widely available to forensic

laboratories; researching potency/binding affinity of confirmed to estimate harm from different compounds before they emerge, and maintaining consistent attention is required for method development and production of accurate and precise analytical results [21,23]. In addition to these proactive responses by laboratories, the emergence of COVID-19 highlighted the importance of surveillance by laboratories in the prevention of harm. Decreased investment in public health, the underinvestment in medical examiners and coroner offices, and underinvestment in testing laboratories contributed to the pandemic [61].

Investing in the sentinel functions of laboratories provides benefits beyond those immediately recognized in the previously described direct measures of harms. These measures of harm are compounded by the severity of the opioid crisis has intensified over the past several years along with a growth in demand for toxicological analysis. Furthermore, the required toxicology testing may be different based on geography and the rural-urban continuum profiles that may have distinctly different drug use patterns [62,63]. Since 2015, overdose deaths in the United States have more than doubled to over 100,000 overdose deaths in 2021 [16]. The opioid share of those deaths continued to increase to roughly three out of every four overdose deaths. Deaths from synthetic opioids, fentanyl, and analogs, increased by 10% over 2018, the only year in the past decade when total overdose deaths fell [64].

The pressures on forensic laboratories from the opioid pandemic contribute to the impact from DUID harms because they erode resources at a rate faster than jurisdictions have been able to redirect budgets. The result from this opioid-related demand for laboratory resources has been an increase in the turnaround time for all laboratory analyses [3,63,65], and those increases in turnaround contribute to the erosion of evidence in casework, including DUID cases [66].

7. Tax revenue and legalization of Cannabis—A decision made

Economic impact studies in the State of Washington anticipated that license and tax revenue would provide an estimated \$300 million to \$350 million annually to state coffers.⁶ Table 2 shows the revenue returns from the initialization of the program through June 30, 2020.

The revenue growth from cannabis tax and fees will continue to grow. Through fiscal year 2022, that growth will raise more than a half billion dollars per year. The original passage of Washington State Initiative 502 (I-502) called for the dedication of much of the revenue to specific causes, including drug education and treatment as an alternative to punitive measures. The budget allocations through fiscal year 2022 will provide 58.1% of the funding to health care, 35.1% to the State General Fund, 0.4% for research and testing, 2.8% for licensing of legal growers and licensing enforcement, 2.9% for local governments, 2.1% for educational materials, and 0.5% to the Washington State Patrol (which includes the Washington State Patrol toxicology laboratory). Although the passage of I-502 relied upon an emphasis toward treatment of substance abuse disorder, the small percentage of revenue dedicated to enforcement was met with doubled DUID cases and a toxicology case backlog that reached 6000 cases.

8. Identifying and acting on emerging trends

Chosen actions, such as the legalization of cannabis, have reactions that are easily anticipated from experience. With legalization, there will be an increase in drug abuse. Any subsequent increase in enforcement efforts will be followed by increased case submission to the toxicology laboratory. Given the length of time that it takes to hire and train additional personnel in the laboratory, proactive hiring can prevent lengthening turnaround times and the resulting backlog problem.

Cutting surveillance of any kind can have negative societal impact. COVID-19 provided a clear indication of the social costs of cutting surveillance. With over 700,000 U.S. deaths from COVID-19 to date, earlier detection and action offers a counterfactual alternative of lives saved. Although many allude to the COVID-19 outbreak as a Black Swan⁷ event, occurring roughly 100 years after the Spanish flu pandemic, a look at the past century suggests otherwise. Several infectious outbreaks could have had more severe consequences, including the 1957–58 Influenza, the 1968–69 Hong Kong Flu, HIV/AIDS from 1981–date,

SARS 2002–04, Swine Flu 2009–10, MERS 2012, Ebola 2014–2016, and Zika in 2016. Each of these events had the capability to expand into a pandemic (CDC, 2018).

Forensic laboratory’s potential surveillance role extends from adequately funding public health to funding for the forensic laboratories, medical examiner, and coroners. The increase in turnaround time means that these laboratories are relegated to a supporting role for court cases and have thus abandoned the sentinel surveillance role that forensic intelligence provides. Given the time lags involved in the identification of new analogs, time to acquire reference samples, and the time to hire and train additional toxicologists, public health and safety suffer.

9. Benefit to Cost and ROI—A case study for laboratory-informed planning of a proactive response in the prevention of harms

Given the complexities of the demands for services from toxicological analyses, return to the question of the benefit-to-cost ratio or ROI from increased investment in DUID analyses. The Washington Traffic Safety Commission collects detailed data on traffic fatalities and the results from testing for alcohol, cannabis, and other drugs. Table 3 breaks down vehicular crashes fatalities with particular focus on incidents of drug and alcohol testing and positive tests for various drugs and the associated conservative social cost estimate.

Note that the Delta-9 THC designation of 5 ng/mL is the *per se* limit in Washington State. This social cost exceeds the total tax and fee revenue generated from cannabis sales in that same year (approximately \$381 million tax and fee revenue in calendar year 2018). Furthermore, the social cost depicted in Table 3 only pertains to the cost from fatalities. Only 0.5% of the revenue generated through legalizing cannabis was given to Washington State Patrol for toxicology testing, including DUID, even though there are insufficient data to extend the social cost to include vehicular crashes only involving injury or property damage.

The benefit-to-cost and ROI metrics depend on case submission to the toxicology laboratory. In turn, case submissions depend on the enforcement of the law via testing of suspected DUID.

Avoiding DUID fatalities depends on increasing surveillance of drivers and testing for the presence of drugs in the systems of those drivers. However, the question is whether such increased surveillance will be economically viable. Suppose the state allocated additional funding to the Washington State Patrol or local law enforcement for heightened DUID checks. As shown in Table 3 for fatalities, 61.9% of individuals who were drug tested resulted in the confirmed presence of drugs. Although we do not know how many drivers operate under the influence of drugs, if increased surveillance found even a small

Table 2
Washington state annual cannabis taxes and fees received following enactment of 2012 Washington state initiative 502 (I-502), 2015–2020.

Year	Cannabis Taxes/Fees* (\$)
FY2015	65,688,344
FY2016	189,219,693
FY2017	319,087,924
FY2018	367,382,493
FY2019	395,523,567
FY2020	473,931,351

Source: (*) Washington Liquor and Cannabis Control Board [67–72]].

⁶ “Washington State Initiative 502 (I-502), effective Dec. 6, 2012, legalized possession of small amounts of cannabis for recreational use by adults aged 21 years and older. It also included a prohibition against driving with 5 or more nanograms of delta-9-tetrahydrocannabinol (THC) per milliliter of blood, along with a zero-tolerance prohibition for drivers younger than 21 years of age” [80].

⁷ A black swan event refers to something unpredictable or an event with an extremely low probability of occurrence beyond normal events but with severe outcomes.

Table 3
Conservative societal cost estimates attributed to Washington state traffic fatalities, 2018.

	Total	Percent of Fatalities (%)	Percent of Drug Tested (%)	Social Cost (\$)
Fatalities 2018	754			7,528,132,792
Tested for Drugs	383	50.8		3,823,971,962
Positive for Drugs (including alcohol)	237	31.4	61.9	2,366,269,856
Polydrug Positive	161	21.4	42.0	1,607,466,021
Alcohol Only	45	6.0	11.7	449,291,745
Single Drug Positive	31	4.1	8.1	309,512,091
Positive for Cannabis	102	13.5	26.6	1,018,394,622
Delta-9 THC Over >5 ng/mL	47	6.2	12.3	469,260,267

Source [42,73]:

percentage (e.g., 1%) of 100 suspected impaired drivers who tested positive for the presence of drugs and avoided a fatality, that single avoided fatality provides a societal benefit of \$9,984,261 (see Table 1). The benefit from cost avoided of \$9,984,261 (i.e., the economic harm per crash, Table 1) would come at a cost to the forensic laboratory of \$40,572. This translates into a benefit-to-cost ratio of \$246 to \$1 or ROI of 24,509%.⁸ The high rate of return for the Washington State Patrol Toxicology Laboratory exceeds the expected return that would come from a smaller caseload. However, a laboratory processing 10% volume of the volume in the Washington State Patrol Toxicology laboratory would boast a benefit-to-cost ratio exceeding \$100 to \$1.

10. Observations and concluding remarks

Any review of the impact of additional funding and expected outcomes for investment in toxicology cases (e.g., DUID, overdose) faces complications from concurrent societal impacts. Washington State's experience highlights some of the difficulties in isolating the demands to the toxicology laboratory from the legalization of cannabis [74,75]. As data on the impact of the law on DUID are revealed, they are confounded by additional changes, including rising opioid use and COVID-19 (CDC, 2021; [15]. Regardless of the source behind DUID involved vehicular crashes, the value that the forensic laboratory plays toward improved public safety is substantial. Jurisdictions looking toward liberalization of laws should anticipate the potential negative effects and plan for additional staffing. The gains from small investments are substantial.

Similarly, consider the other demands on toxicological services matters. Over the past 2 decades, evaluations of the demands for toxicological testing have emphasized concerns over the sustainability of current methodologies to overcome analytical issues. Concerns include time for method validation for new compounds, the increased scope of testing required on each case, the sensitivity of instrumentation, and unacceptable turnaround times that prolong the investigation. The demand for an increase in number, knowledge, and expertise of staffing required for testing compounds these concerns [2]. The adoption of new testing methodologies, which requires more staffing, is the best way to satisfy analytical requirements and remain responsive to emerging toxicological threats [76]. Likewise, the increased demand for toxicological services requires adequately trained individuals and is essential to managing current workloads [2,77]. A new analyst in a forensic toxicology laboratory usually qualifies for work with a minimum of a 4-year undergraduate degree in a natural science such as chemistry, pharmacology, or biology and needs an additional 1 to 3 years to be fully trained in analytical and toxicological concepts and methods. Similarly, toxicologists require a discipline-specific graduate program and additional laboratory and expert witness experience. To become board-certified in this field, still more training, testing, and continuing education are required [78,79]. Demand for services is trending upwards, and plans for the moving target of increasing caseloads can be anticipated. Proactive staffing, rather than delayed reactions, have positive impacts for society via public safety and public health.

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⁸ The cost of \$40,572 reflects the economies of scale of the Washington State Patrol Toxicology laboratory with a caseload volume of approximately 11,000 and a cost per case of approximately \$405.72. The benefit-to-cost ratio is \$9,984,261/\$40,572 and the ROI is (\$9,984,261 - \$40,572)/\$40,572.

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