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Drug Detection, Analysis, and Monitoring Workshop Report

Edward Sisco

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Edward Sisco
Materials Measurement Sciences Division
Material Measurement Laboratory

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Author ORCID iDs
Edward Sisco: 0000-0003-0252-1910

Contact Information
edward.sisco@nist.gov

Abstract

This report is a summary of a workshop convened to capture the analytical and data challenges inherent to the detection, identification, and monitoring of illicit drugs in the United States – specifically highlighting current practices, challenges, and opportunities for growth within communities. It systematically examines each stage of the analytical and data workflow, from sample recognition and collection to data dissemination, outlining opportunities to improve existing procedures and technologies. Recognizing the tradeoffs between the need for rapid results and the need for high confidence in those results, the report explores emerging technological solutions, standardization efforts, and training opportunities for enhancing drug detection and analysis. Furthermore, the report explores the complex landscape of data aggregation and dissemination, highlighting the need for standardized data structures, robust data-sharing, and clear communication strategies to effectively leverage data for informed decision-making and public education. Finally, the report presents potential action items for NIST to leverage its expertise in measurement science, standards development, and community engagement to assist in mitigating the challenges posed by the evolving drug landscape.

Keywords

Analytical Chemistry; Data Science; Drugs; Forensic Science; Law Enforcement; Public Health; Standards; Synthetic Opioids.

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Acknowledgments

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Executive Summary

The drug overdose epidemic continues to exact an enormous toll on the American public. Since the dramatic increase in overdose deaths began in 2013, driven by illicitly manufactured fentanyl, fatal and nonfatal overdoses have continued to climb. While the rise of fentanyl prevalence in the drug supply continues to be worrisome, the constant influx of new substances into the supply, such xylazine, nitazenes, and designer benzodiazepines, has further complicated efforts for all communities in working to address this challenge.

In December 2023, the Testing, Rapid Analysis, and Narcotic Quality (TRANQ) Research Act was signed into law, directing NIST to increase research, standards development, and convening efforts related to fentanyl adulterated with xylazine as well as other emerging compounds of concern. In response to the Act, NIST hosted a workshop in February 2024 to bring together members from as many communities working in this space as possible to better understand the analytical and data challenges being faced. This report is a summary of the challenges that were identified and potential solutions that NIST and others could work to implement over the coming years.

During the two-day workshop members from seven broad communities (customs and border interdiction, public health and harm reduction, law enforcement and first responder, forensic science, emergency medicine, medical examiner and coroner, and policymaker) shared their perspectives on the current state and opportunities for improvement within their fields. Many of the challenges facing workshop participants were not unique to one community, and several major challenges were found to be universally observed by everyone present. To simplify dissemination of the main themes and takeaways from the workshop, the current state, challenges, and opportunities for advancement are separated in this report into six components of the drug analysis chain:

1) **Sample collection –** identifying what sample to collect and how to best collect it.

   Major challenges identified include lack of best practices for sample collection and transportation, absence of legal clarity for harm reduction drug checking efforts, and time delays between sample collection and submission to a laboratory. Several challenges in the customs setting, driven by de minimis shipments, were also highlighted.

   Opportunities for advancement identified include development of consensus best practices for collection and transportation and increased research investments in non-intrusive inspection technologies.

2) **Sample analysis –** using analytical instruments to interrogate a sample.

   Major challenges identified include the lack of standard methodologies and protocols, sparse or nonexistent method validation resources, technology with insufficient sensitivity and specificity, and discrepancies between vendor claims and real-world instrument performance.

Opportunities for advancement identified include development of documentary standards, incentivization of researchers to work more closely with end-users, and the creation of a centralized, collaborative hub for technology and method development, testing, and validation.

3) **Data interpretation –** interpretation of the analytical data to identify the substances present in a sample.

   Major challenges identified include lack of physical reference standards and reference data, difficulties in differentiating structurally similar compounds, limited tools to assist in identifying unknown compounds, data interoperability issues, and poor understanding and conveyance of the limitations for certain technologies.

   Opportunities for advancement identified include open access reference data, development of new algorithms to increase the objectivity and accuracy of data interpretation, new approaches for unknown identification, and a centralized QA/QC training program.

4) **Immediate action –** using the results of a single analysis to take an action.

   Major barriers identified to take action included data that is incomplete or not timely, as well as staffing, technology, or resource constraints.

   Opportunities for advancement identified include ensuring the testing being completed is reflective of the current drug landscape, encouraging comprehensive reporting of chemical results, increasing the use of machine learning for data interpretation, and modifying workflows and analytical methods to address backlogs.

5) **Data aggregation –** collating results from multiple analyses, sources, or communities.

   Major challenges identified include merging data that has different architecture, inconsistent drug naming, data sharing and privacy concerns, lack of surrounding data limitations, and the need for processes to handle large, complex datasets.

   Opportunities for advancement identified include development of a consensus-based data architecture and drug nomenclature, creation of best practices for desensitizing and sharing data, increasing transparency of data limitations, and advancing the use of AI and machine learning in data aggregation and interrogation.

6) **Data dissemination –** conveying aggregated data to one or more communities or the public.

   Major challenges identified include conveying statistical relevance and limitations of data in a digestible manner, ensuring information is presented in an equitable and accessible format, preventing alert fatigue, and ensuring data is not misused in a harmful manner.

Opportunities for advancement identified include development of best practices for data sharing to ensure it is accessible and engaging, developing guidelines for communicating data blind spots and limitations, and harmonizing the formatting of dissemination products to the public.

Based on the discussions within the workshop, five areas were identified where NIST could assist the represented communities to address analytical and data challenges and meet the requirements outlined in the TRANQ Research Act. These include: i) advancing analytical measurements, ii) creating next-generation data analysis tools, iii) development of standards (physical, reference, and documentary), iv) increased education and training, and v) continued convening of personnel from all communities involved in addressing the drug overdose epidemic.

1. Introduction

1.1. Motivation for the Workshop

The drug overdose epidemic continues to exact a high toll on the American public. In 2023, drug overdoses claimed at least 107,000 lives, the vast majority due to synthetic opioids[1]. For Americans age 18 to 45, fentanyl overdose is the leading cause of death[2]. The high level of overdose deaths is further complicated by a startling number of non-fatal overdoses. The National Highway Traffic Safety Administration (NHTSA) Nonfatal Drug Overdose Surveillance Dashboard reported over 500,000 non-fatal overdoses during the period of May 6, 2023 – May 5, 2024[3]. Naloxone, an opioid reversal agent, was administered more than 220,000 times during the same period[3]. Curbing overdose numbers will continue to be a challenge as the supply of drugs entering the U.S. remains high. U.S. Customs and Border Protection (CBP) seized 249,000 kg of drugs in fiscal year 2023 — including 37,800 kg of cocaine, 63,500 kg of methamphetamine, and 12,250 kg pounds of fentanyl[4]. Interdiction of drugs by law enforcement within the U.S. resulted in nearly 650,000 submissions to forensic seized drug laboratories for testing in 2022[5]— taxing laboratory systems already facing high backlogs[6]. From a financial perspective, drug overdoses had an economic impact of nearly $1.5 trillion in 2020[7], with the U.S. government spending over $43 billion on drug control in fiscal year 2023[8].

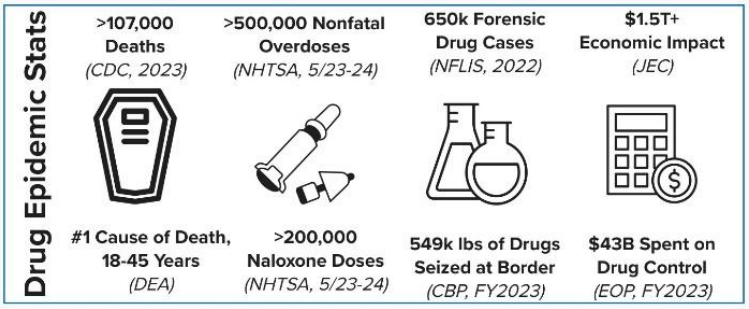


Figure 1. Summary statistics of the drug overdose epidemic.

While NIST may not be front of mind when one thinks about the drug epidemic, efforts in illicit drug research have been longstanding, though largely focused on the forensic science community. Since 2016, NIST has funded internal research projects focused on addressing measurement science challenges in this space. Efforts have included development of new analytical methods[9], algorithms[10–13] and spectral databases[14, 15], supporting new technology implementation[16], creation of quality assurance programs[17, 18], and foundational research in cannabis breathalyzers[19, 20]. Cross-cutting efforts to inform safe handling of highly potent substances have also been a focus[21–23]. More recently, internal research efforts have expanded to address the needs of the public health and law enforcement agencies through a near real-time drug checking collaborative[24, 25].

On December 19, 2023, the TRANQ Research Act[26] was signed into law. The Act calls upon NIST to increase its efforts in fundamental research and convening of communities focused on addressing the overdose epidemic to support detection, identification, and understanding of

novel synthetic opioids and other compounds of concern. In response, NIST organized the workshop to serve two purposes – to inform a roadmap for future efforts at NIST that reflect the needs of the community and to begin dialogue between communities involved in addressing the drug epidemic that may not frequently collaborate.

1.2. Workshop Overview

To capture the needs of communities at the forefront of the drug overdose epidemic, NIST held an in-person workshop titled, "Analytical and Data Challenges Surrounding Drug Detection, Identification, and Monitoring" on February 13–14, 2024. The workshop gathered members from customs and border interdiction, public health and harm reduction, law enforcement and first responder, forensic sciences, emergency medicine, medical examiner and coroner, and policy communities to discuss analytical and data challenges in drug detection, analysis, and monitoring. Workshop participants included local, state, and federal government agencies, academics, and non-governmental organizations. For this workshop, industry was not represented.

The workshop agenda, outlined in Appendix A, encompassed an opening plenary with speakers from the Office of National Drug Control Policy (ONDCP), CBP, and Centers for Disease Control and Prevention (CDC) to describe the current state from a policy, customs and law enforcement, and public health perspective. The remainder of the first day explored analytical challenges in field, laboratory, and post-mortem settings. The second day featured a series of presentations focused on data challenges from the perspective of the seven communities represented. Speakers, except for the opening plenary, were provided with a standard slide template with prompts to frame their presentations to better capture similarities and differences in challenges faced. A copy of those prompts is provided in Appendix C. To facilitate discussion, the workshop participation was limited to 45 individuals. Roughly a third of participants were NIST staff. A complete list of participants can be found in Appendix B.

2. Communities Represented

The workshop was designed to include members from as many different communities involved in drug detection, analysis, and monitoring as possible. For simplicity, they have been binned into seven communities – customs and border interdiction, public health and harm reduction, law enforcement and first responder, forensic science, emergency medicine, medical examiner and coroner, and policy makers. While the specific missions of all the communities are unique, they share an overarching goal – to protect the American public from the danger of illicit drugs.

The following subsections provide a brief overview of the mission, representative agencies and organizations, and main goals for the seven communities.

2.1. Customs & Border Interdiction

Drug-Related Mission: To stop illicit drugs and other compounds of concern from entering the country through ports of entry.

The customs and border interdiction community is focused on preventing illicit drugs, precursors, or drug manufacturing equipment from entering the United States. These efforts occur at the border – which includes the northern and southern land borders, seaports, coastlines, airports, and international mail facilities. Given that tens of thousands of people and millions of packages enter the U.S. daily, interdiction efforts rely heavily on intelligence and non-intrusive inspections (NII) to identify and intercept illegal transport.

The customs and border interdiction community consists of CBP as well as several other federal agencies such as the Food and Drug Administration (FDA), the United Stated Postal Inspection Service (USPIS), and the Drug Enforcement Administration (DEA). These agencies operate in a range of environments– from desert-like conditions at the southwest border crossings to major seaports like Miami to large warehouses where packages from around the world are delivered and sorted. The variability in the environment in which drugs may be encountered present unique challenges for field agents, necessitating analytical testing that can withstand a variety of harsh conditions and settings.

This community aims to identify whether an encountered substance is illegal and, if so, seize it for destruction and/or prosecution. A presumptive identification of a substance may be sufficient to determine if something should be seized, but there are instances where additional laboratory based confirmatory testing is required. With many of the new drugs being synthesized outside of the U.S.[27–29], this community is often the first to encounter new drugs or compounds of concern.

2.2. Public Health & Harm Reduction

Drug-Related Mission: To inform people who use drugs (PWUD), as well as the public, of the risks associated with illicit drugs and provide resources to reduce the risk of harm or overdose.

Public health and harm reduction agencies and organizations are focused on providing PWUD, in addition to the public, information and resources to lower the harms of illicit drug use. The leading federal entities in this area are CDC and the Substance Abuse and Mental Health Services Association (SAMHSA), both of whom fund drug checking and overdose prevention efforts at the state and local level. These agencies also aggregate data from state and local entities to drive policy and promote community awareness.

Public health efforts related to drug use vary widely across states, largely driven by differences in legal frameworks. State, county, or city public health organizations collate information on drug use, non-fatal overdoses, and fatal overdoses to understand the magnitude and trends in their geographic region. They administer resources and intervention tools like naloxone, fentanyl test strips, and drug use supplies (*e.g.*, syringes, cookers, etc.) to promote safe use practices and reduce overdose risks. They also act as a community liaison, sending out alerts when there is a change in the drug supply or the appearance of a new drug. These agencies often rely on data collected from a variety of sources to drive decisions and messaging.

Harm reduction is a more focused component of public health that provides direct tools and resources to PWUD. These efforts may take place under the department of public health or may be independent organizations or academics[30]. Harm reduction efforts often take place in needle exchange sites or syringe services programs, which can be mobile platforms or brick and mortar facilities. In these environments, personnel interact one-on-one with PWUD to provide services (addiction treatment or wound care), supplies (naloxone, clean syringes), and information (safer use practices). Many of these sites also offer drug checking services, where PWUD can gain immediate or retrospective information about the drug(s) they consume. This testing can be done on-site, with technologies like fentanyl test strips or Fourier transform infrared spectroscopy (FTIR), or by sending a small sample of the drug product, or used paraphernalia, to a laboratory for testing.

The main goal of drug checking is to identify if a sample contains a drug that may put the PWUD at increased risk. This community often relies on presumptive identification to provide indications to PWUD that compounds of concern (*i.e.*, fentanyl or xylazine) may be present in a sample. Some drug checking programs will also leverage laboratory based testing to get more in-depth and specific information about the makeup of the local drug supply. These results will also often feed into larger scale epidemiological surveillance efforts. Since the drug checking community works directly with PWUD, they are often the first to be alerted to changes in the drug supply, through conversations with PWUD about their experience with using a particular drug sample.

2.3. Law Enforcement & First Responder

Drug-Related Mission: To reduce the prevalence of drugs in a community and protecting the public from the dangers associated with illicit drug use, distribution, and manufacturing.

Law enforcement entities are primarily focused on reducing the dangers of illicit drug use, distribution, and manufacturing to the public through first aid, enforcement, and investigation.

Agencies are present at all levels (local, state, and federal) and employ a variety of tools for illicit drug detection. The operational environment for this community is typically the roadside or other non-laboratory environments, which requires rugged and rapid analytical tools that produce easily interpretable data. From an enforcement and investigation perspective, presumptive identifications are typically sufficient to take initial action such as making an arrest and seizure. Samples are then submitted to forensic laboratories for confirmatory analysis, the results of which may be used in criminal prosecution.

First responders, which include fire, emergency medical services, and law enforcement, focus on ensuring public safety in the event of an overdose or hazardous material situation. For overdoses, this typically means providing first aid and supportive care during transport to a hospital. First responders are often called to scenes where the presence of hazardous materials may be suspected, such as a clandestine laboratory or a location where drugs are cut (the process of adding diluents, adulterants, and other compounds to the pure drug) and packaged. In these instances, the focus is on identifying what hazards exist and neutralizing them. Screening techniques are commonly employed to obtain presumptive identifications, with results used to determine the necessary containment and cleanup efforts. This operational environment requires analytical tools that can be operated while wearing significant levels of personal protective equipment (PPE) and provide easily interpretable results.

There are several data aggregation efforts within law enforcement and first responder communities. Most notable are the High Intensity Drug Trafficking Areas (HIDTA) groups[31], which are organizations consisting of tribal, local, state, and federal law enforcement personnel that focus on disrupting drug markets and drug trafficking in targeted geographical areas. The DEA, CBP, and Homeland Security Investigations (HSI) also have data aggregation efforts and many states have fusion centers, which incorporate public health data into their aggregation and dissemination efforts.

2.4. Forensic Science (Seized Drug & Toxicology)

Drug-Related Mission: To determine which substances are present in a suspected drug product or biological sample submitted to the laboratory.

Forensic science entities are primarily focused on the qualitative and/or quantitative identification of illicit drugs in suspected drug products or biological samples, referred to as seized drug analysis and toxicology, respectively. Law enforcement entities, medical examiners, or coroners submit these samples for analysis. Because the results of forensic testing are often used in criminal prosecutions, confirmatory analyses are typically also conducted. Workflows in this community require the use of multiple analytical techniques to verify the identity of a drug within a sample. Most forensic laboratories are accredited by a nationally recognized accrediting body and therefore have quality assurance systems in place.

For this report, the seized drug analysis and toxicology components of forensic laboratories have been grouped together, though their missions and methodologies differ. The focus of the seized drug unit is to analyze the actual drug substance or paraphernalia containing the substance submitted to the laboratory. Since the actual substance is being tested, sample

preparation is typically more straightforward than toxicology (where biological samples are analyzed), and instrument sensitivity is less of a concern (since there is often bulk material available). Most analyses are qualitative in nature to determine only if an illicit drug is present; though there are instances when quantitative assessment, or how much of the illicit drug makes up the substance, is required. The field of seized drug analysis is guided heavily by the Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG)[32], an international working group that develops best practices, analytical workflows, and reference data for the community. There is also a seized drug subcommittee[33] within the Organization of Scientific Area Committees (OSAC) that develops consensus standards and recommendations for laboratories in the United States.

Forensic toxicology involves the identification of illicit drugs within biological matrices for ante-mortem and post-mortem cases. The concentration of illicit drugs in biological fluids is typically low, necessitating the use of highly sensitive analytical instrumentation and, at times, extensive sample preparation protocols. In this discipline, quantitative analysis is often completed to determine impairment or cause of death. The development of toxicological standards and recommendations in the United States is spearheaded by the forensic toxicology subcommittee[34] within OSAC.

2.5. Emergency Medicine

Drug-Related Mission: To treat patients who are experiencing an overdose or adverse health condition from exposure to illicit drugs.

The emergency medicine community's focus is on the treatment of patients who are presenting signs of drug exposure or an overdose. While much of the initial triage and treatment is based on the ailments of the patient[35], emergency medicine does collect biological specimens for clinical toxicology purposes. These tests are used to determine what substance(s) a patient has consumed. Clinical toxicology testing may occur within the hospital but may also be outsourced to a commercial testing laboratory. This type of testing is usually panel-based, requiring clinicians to determine the appropriate panel of drugs to screen for.

This community utilizes urine screening testing as well as confirmatory laboratory based clinical toxicology depending on the situation. This data is oftentimes retrospective, meaning the patient has been discharged from the hospital prior to receiving test results. The data generated by this community is used to feed data aggregation efforts at the state and national levels.

2.6. Medical Examiner & Coroner

Drug-Related Mission: To identify what drug(s) a decedent consumed and determine if those substances contributed to the cause of a fatality.

The medical examiner and coroner community is primarily focused on the determination of cause of death for decedents, including those related to drug overdoses or poisonings. The death investigation is comprised of three components – scene investigation, autopsy, and post-

mortem toxicology. The scene investigation is used to establish the circumstances of death, obtain medical history, and identify if drug paraphernalia, drug product, or other indicators of drug use are present where the decedent was found. Autopsy results are used to identify signs of a fatal overdose in the body, during which biological samples are collected for testing by post-mortem forensic toxicologists. Toxicology testing may be completed in-house or outsourced to a commercial laboratory. Like clinical toxicology, this type of testing is often panel-based.

For this community, quantitative confirmatory toxicological analysis is required to assist in determining the cause of death. This information is used in conjunction with the scene investigation and autopsy in the issuance of a death certificate.

It is important to note that medical examiners and coroners differ in their roles and abilities. Medical examiners, also known as forensic pathologists, are highly trained medical doctors that have extensive training in investigating bodies for cause of death. Coroners are appointed or elected officials that certify the cause of death. Coroners may or may not have medical backgrounds or specialized training. The prevalence of medical examiners and coroners varies across the country[36] (**Figure 2**).

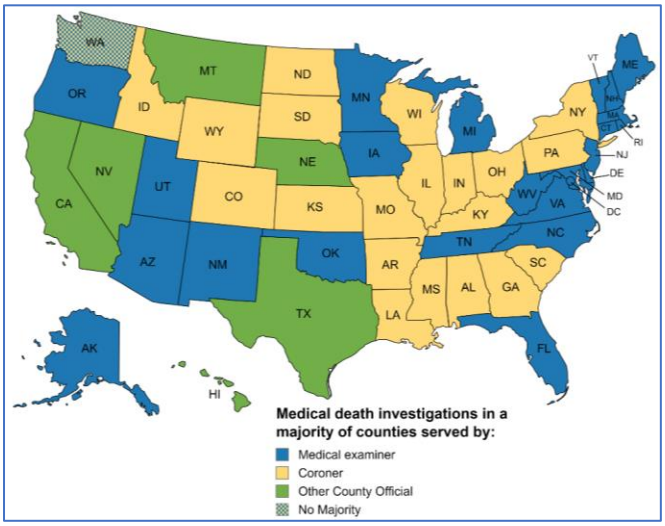


Figure 2. Depiction of the type of medical death investigation that is most common in each state[36].

Data generated by medical examiners and coroners are used by local, state, and federal entities to monitor drug overdose trends geographically and temporally. From a federal perspective, CDC is the main agency responsible for aggregating this data[37].

2.7. Policymaker

Drug-Related Mission: To establish and implement laws or policies that lower the dangers presented by illicit drugs for the public, while increasing the safety of PWUD.

Policymakers focus on establishing laws and policies to help address the many challenges brought by the drug overdose epidemic. While policymakers do not perform drug analysis or

generate data of their own, they use data from all other communities to inform decision making and evaluate the efficacy of enacted policies.

From a federal perspective, policy is driven by ONDCP. This office is charged with developing and implementing the National Drug Control Strategy[38] and associated budget. ONDCP also coordinates efforts across federal agencies tied to drug interdiction and treatment, funds the HIDTA program, and is responsible for identifying when new threats emerging in the illicit drug supply (an example of which is fentanyl adulterated with xylazine[39]). Policymakers at the state and local levels also have significant efforts in addressing and implementing interdiction and treatment strategies within their own jurisdictions.

3. Current State, Challenges, & Opportunities

The following two sections discuss the current state, current challenges, and potential opportunities for advancement related to the analytical and data components of the illicit drug detection, identification, and monitoring chain. For simplicity, the chain has been condensed into six steps (**Figure 3**). The first three steps (analytical) are those necessary to generate data that can be acted on and are discussed in the following section, **Section 4**. The remaining three steps focus on what is done with the data and are discussed in **Section 5**. A description of each step is included below.

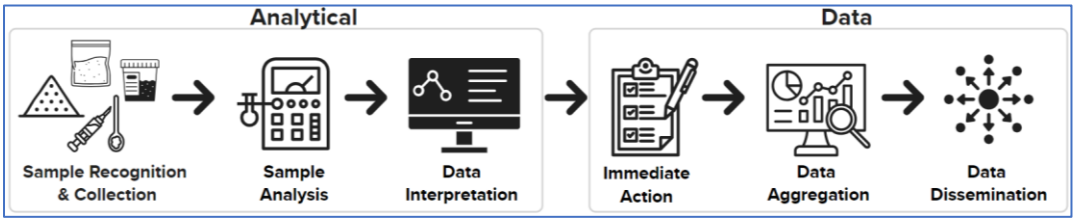


Figure 3. Breakdown of the drug workflow sections discussed in this report.

*Sample Recognition and Collection (**Section 4.1**)*: Identifying what sample(s) should be analyzed and determining how quickly results are needed. This also includes collecting, and in some instances transporting, the sample for analysis.

*Sample Analysis (**Section 4.2**)*: Completing chemical analysis of the sample, in the field or in the laboratory. This includes sample preparation, if necessary.

*Data Interpretation (**Section 4.3**)*: Evaluating the resulting analytical data to determine if a drug is present, what drug is present, and/or how much drug is present.

*Immediate Action (**Section 5.1**)*: Acting on the data generated from a single sample or case (*i.e.*, determining whether to seize a package at the border or determining cause of death from toxicology results).

*Data Aggregation (**Section 5.2**)*: Collation of data from multiple sources to gain additional insights for a broader question (*e.g.*, trend analysis, forecasting, data mining).

*Data Dissemination (**Section 5.3**)*: Sharing the results of aggregated data, and sometimes of a single piece of data, with other communities or the public so that additional actions can be taken (*i.e.*, informing the public on the presence of a new synthetic opioid or public health departments deciding where to increase overdose prevention efforts).

The following two sections are structured as follows. First, a high-level overview of the different components of the analytical or data chain is provided to highlight the interconnectedness, or lack thereof, between communities. Each step is then discussed. An outline of the current state of the step is presented following current challenges that were identified in the workshop and concluding with potential opportunities for how that step could be improved. As a reminder, this report focuses only on the analytical and data components of the illicit drug lifecycle, and it does not address policy, ethical, or social challenges unless they are directly tied to analysis or data use.

4. Current State, Challenges, & Opportunities – Analytical

There are two broad types of analysis that are conducted on drug samples – screening and confirmation. Screening analyses are completed to obtain an initial, often presumptive identification of what drug or class of drug may be present in a sample. These analyses are often conducted in the field, where results are needed quickly to inform decision making. Generally, false positives are more tolerable than false negatives in these scenarios as they trigger the need for additional, confirmatory testing or initiate procedures to minimize harm to individuals. On the other hand, confirmatory analyses often require expensive instrumentation, minimal to extensive sample preparation, and lengthy analysis times. These analyses are completed in a laboratory setting and focus on rigorous identification of the exact drug(s) in the sample. Unlike screening analyses, the goal is to minimize false positives as much as possible.

Most communities leverage a combination of screening and confirmatory techniques in their analysis chains. This is demonstrated in the flowchart below (**Figure 4**), where the movement of the physical drug and its lifecycle is shown vertically (beginning with synthesis at the top and ending with consumption that leads to a fatal overdose at the bottom) and the analysis chain is shown horizontally (beginning with non-chemical data collection on the left and confirmatory analysis on the right). Blocks are colored based on the community completing the analysis.

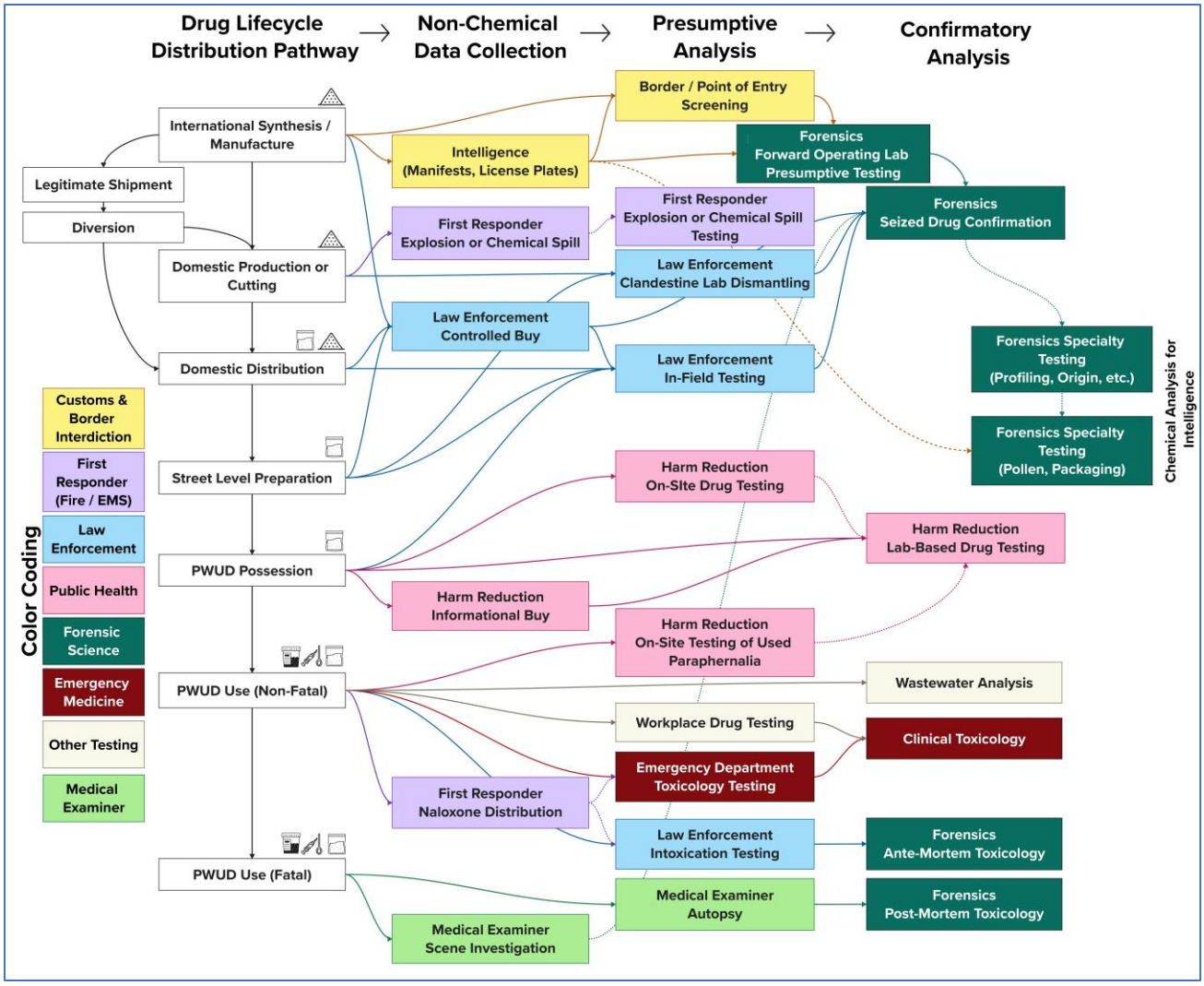


Figure 4. Drug distribution and analysis flowchart.

At each point in the drug lifecycle, and at each step in the analysis chain, personnel must decide what, if any, sample to collect, how to analyze the sample, and how to interpret the data before taking an action. Each of these three steps contains challenges that must be acknowledged and/or overcome. It is also important to note that each community may handle these steps differently depending on their mission and the question they are trying to address.

4.1. Sample Recognition & Collection

4.1.1. Current Status

There are four ways drug samples may be presented to communities involved in drug detection – as a pure drug or precursor for synthesis, a street-level drug (one or more drugs mixed with cutting agents or diluents), a drug residue (typically in the form of used paraphernalia), or within a biological matrix (**Figure 5**). Pure drugs and precursors are most frequently

encountered by customs personnel as bulk powders or liquids that may be concealed in goods, vehicles, or people that are entering the country. First responders and law enforcement may also encounter these substances when responding to reports of clandestine laboratories or packaging operations. Street-level drugs are frequently encountered by public health, public safety, and law enforcement personnel who interact with PWUD or street-level dealers. Customs and border interdiction may also encounter these substances as packages or shipments being sent through the mail or another border point. Drug residue – trace amounts of drug material present in used drug paraphernalia – are commonly encountered by public health, public safety, and law enforcement who directly interact with PWUD and medical examiners who encounter used paraphernalia at overdose scenes. These scenarios include needle exchange sites and traffic stops. Biological samples are often collected in law enforcement, emergency medicine, and medical examiner settings to determine impairment or the cause of an overdose. Forensic science testing can occur using all sample types since this testing supports the other communities. Samples are rarely collected by the forensic science community.

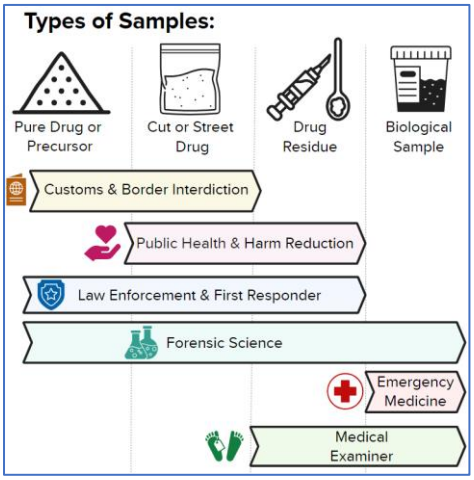


Figure 5. Pictorial representation of the types of drug samples encountered by each community.

Recognizing samples to analyze is often completed through visual observation of a person or a scene, such as inspection of a vehicle at a traffic or border crossing or watching someone who is visibly impaired. For some public health settings, especially those surrounding harm reduction and community drug checking, PWUD may provide samples directly to personnel, eliminating the need to determine which samples to test. For certain scenarios, such as customs and border interdiction, the use of non-chemical data (shipping manifests or vehicle license plates) can help identify samples that should be collected.

Collection procedures often vary depending on the community and type of sample. Customs or law enforcement may encounter large amounts of a suspected drug and need to identify ways to safely store and transport potentially lethal substances. They may also have to determine the best way to subsample a portion of the item for testing. Public health workers and medical examiners may collect used syringes for testing, where accidental exposure to bloodborne pathogens may present the greatest risk. Emergency medicine personnel may have to collect a biological specimen from someone who is unwilling to provide it.

4.1.2. Challenges

While sample recognition and collection may seem straightforward, there are notable challenges, especially within customs and public health. One universal challenge entails the collection, transportation, and analysis of potentially harmful samples while maintaining personnel safety. As the potency of these compounds increases, the development and implementation of safe handling practices are more important than ever. Safe handling practices protect personnel from biological hazards when handling paraphernalia or biological samples. Effective protocols will also protect against cross-contamination of samples, which can occur from improper storage. While safe handling practices exist for some communities[40–44] others offer little to no guidance at all.

A unique sample recognition challenge encountered by the customs and border interdiction community is de minimis shipment. De minimis shipments are small, low dollar value packages that are consolidated into larger packages or containers prior to entering the U.S., duty-free[45]. De minimis shipments represent a large number of items entering the country – nearly 700 million de minimis packages entered the U.S. in 2022[46]. Yet, unique manifests for each of the smaller packages are often non-existent, making it difficult to identify the contents of packages entering the country and their final destinations. This lack of information makes it difficult to develop the intelligence needed to identify packages that may contain drugs.

A collection challenge within the public health community revolves around a lack of clarity in many jurisdictions with respect to what is, or is not, considered drug paraphernalia or a drug sample. Similarly, multiple attendees highlighted legal barriers that prevent access to drug samples from PWUD in harm reduction settings because of state definitions of drug paraphernalia that include fentanyl test strips. Public health entities that partner with laboratories for confirmatory analysis also expressed concern over the lack of clarity around what types of samples can and cannot be mailed – from both a legal and safety perspective. As this community is heavily reliant on obtaining samples from PWUD, this can be a deterrence to action from fear of law enforcement encounters.

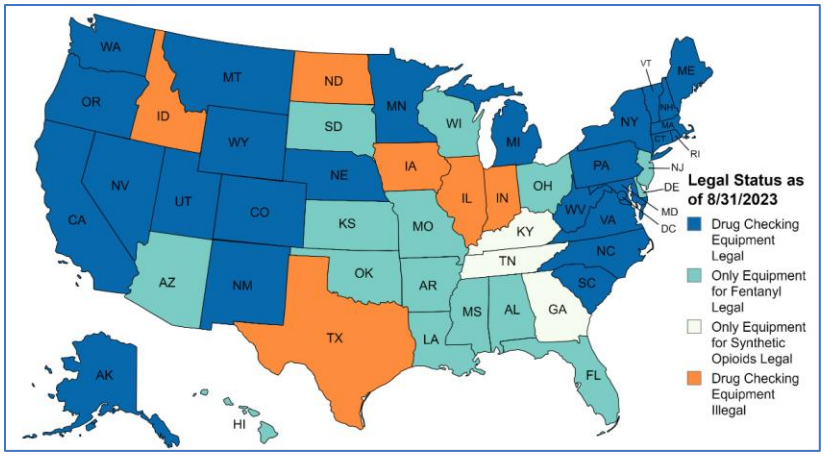


Figure 6. Legal status of drug checking equipment in the U.S. as of August 31, 2023[47].

An interesting challenge highlighted by personnel involved in laboratory testing was the delay in time between seizure or collection of a sample to the date a sample was submitted to the laboratory. While testing backlogs are well documented[6] and can lead to lags in reporting, it is worth noting that delays can be further perpetuated by a delay in sample submission. For certain sample types, like plant material, timeliness is also critical to ensure viability of the sample – which can decay if not stored properly.

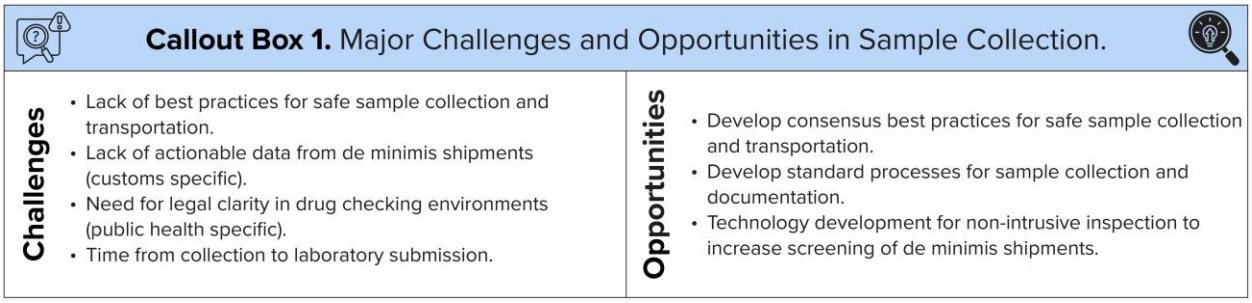
4.1.3. Opportunities

Several opportunities exist to address the challenges highlighted in the previous section. To better ensure personnel safety when handling, transporting, or testing suspected drug samples, a working group could be established to draft consensus-based best practices for safe handing. Some organizations have released guidance on safe handing, including the National Institute of Occupational Safety and Health (NIOSH)[40] and the American Academy of Forensic Sciences[48]. Building on those, in conjunction with new research, cohesive best practices could be developed. To increase the impact of this work, the best practice could be accompanied by training videos to demonstrate potential exposure risks and proper PPE use, mirroring previous efforts in forensic science and other spaces[21–23].

Addressing public health concerns surrounding access to samples would require increased coordination and collaboration between law enforcement and public health entities within jurisdictions to ensure people who are seeking drug checking are able to do so safely. This would also require changes to drug laws within certain states that would allow these types of services to operate. Model drug laws have been drafted by the Legislative Analysis and Public Policy Association to support these efforts[49].

Better information on de minimis shipments would also require changes to laws and policies related to manifesting and declaration. From a technological standpoint, it is possible that advances in NII technology coupled with artificial intelligence could enable screening of higher volumes of packages without manual intervention. Advances in NII would also assist customs and border interdiction efforts at other ports of entry.

Another opportunity to assist in sample collection efforts is to standardize the process and documentation for sample collection within, and across, communities and use cases. For instance, a common approach for the collection, packaging, and documentation of a suspected drug sample in a law enforcement setting could lower exposure risks for officers, streamline sample intake at forensic laboratories, and simplify data aggregation efforts for data dissemination.



4.2. Sample Analysis

4.2.1. Current Status

There are a wide range of analytical tools currently used for screening and confirmatory analyses that vary widely in their specificity, sensitivity, cost, analysis time, and limitations. An overview of some of the most common analytical tools in use are presented in the **Table 1**.

Table 1. Types, characteristics, and limitations of technologies used in drug analysis.

Technology	Characteristics	Communities Sample Types	Limitations
Screening Techniques			
Lateral Flow Immunoassay Test Strips (LFI) [50–56]	• Provides a yes/no result. • Specific to one, or a few, compounds. • Able to analyze drug material and biological samples. • Cost: $ • Time: <5 min / analysis.	 	• May not detect all compounds of interest. • Benign compounds may produce false positives. • Batch-to-batch variability concerns[50]. • Sensitivity of test means it can detect trace background.
Color Tests [57–60]	• Most tests rely on personnel to interpret visual color changes. • Requires a significant amount (>10 mg) of material. • Specific to one, or a few, compounds. • Cost: $ • Time: <2 min / analysis.	 	• Some tests use toxic chemicals. • Limited published research on whether non-target drugs will elicit positive results. • Multi-component samples can produce conflicting results. • Handling of bulk material in field can present safety concerns.
Portable Fourier Transform Infrared Spectroscopy (FTIR) [61–64]	• Transportable and field deployable. • Most systems have simplified user interfaces. • Capable of detecting major components in mixtures. • Requires a significant amount (>10 mg) of material. • Most systems have extensive spectral libraries. • Cost: $$ • Time: <2 min / analysis.	 	• Limited utility in detecting minor components in a mixture. • May not detect all compounds in a complex sample. • Requires interpretation of spectra and spectral results. • Technique is library dependent, leading to difficulty in identifying unknowns.
Portable Raman Spectroscopy [65–67]	• Transportable and field deployable. • Most systems have simplified user interfaces. • Capable of detecting major components in mixtures. • May not require removing the sample for analysis – can analyze through clear plastic or glass. • Requires a significant amount (>10 mg) of material.	 	• Limited utility in detecting minor components in a mixture. • May not detect all compounds in a complex sample. • Requires interpretation of spectra and spectral results. • Technique is library dependent, leading to difficulty in identifying unknowns. • May require laser-specific safety considerations.

	• Most systems have extensive spectral libraries. • Cost: $$ • Time: <2 min / analysis.		
Fieldable Mass Spectrometry (MS) [64, 68, 69]	• Transportable and field deployable. • Most systems have simplified user interfaces. • Capable of detecting major and minor components in mixtures. • Able to analyze both trace and bulk amounts of material. • Cost: $$$ • Time: <2 min / analysis.	 	• Prone to carryover or overconcentration. • Systems have limited spectral libraries. • Complex mixtures may produce inconsistent results. • Often unable to differentiate isomers due to lack of chromatography.
Ambient Ionization Mass Spectrometry (AI-MS) [70–73]	• Typically fixed location systems with more complex operation. • Excellent for trace non-targeted screening analysis. • Fragmentation data may assist in identification of unknowns. • Some tools are available for unknown classification / identification. • Cost: $$$ / $$$$ • Time: 2 min / analysis.	 	• Lack of chromatographic separation can increase data complexity. • Often unable to differentiate isomers due to lack of chromatography. • Systems may have limited spectral libraries. • Limited commercially available, out of the box options.
Canine [74–76]	• Extensive, consistent training required. • Capable of detecting substances without having to open or directly handle packages. • Cost: $$ • Time: Instantaneous.	 	• Cannot analyze samples in a continuous fashion. • Canines are often trained to detect a specific set of drugs. • The exact chemical profiles that trigger a detection are not well understood.
Confirmatory Techniques			
Benchtop Fourier Transform Infrared Spectroscopy (FTIR) [77–79]	• Easy to operate. • Capable of detecting major components in mixtures. • Ability to differentiate isomeric compounds and identify the salt form of a drug. • Extensive spectral libraries. • Cost: $$ • Time: <2 min / analysis.	 	• Limited utility in detecting minor components in a mixture. • May not detect all compounds in a complex sample. • Technique is library dependent, leading to difficulty in identifying unknowns.
Enzyme Immunoassays [78, 80, 81]	• Easy to operate. • High sensitivity, making it useful for toxicology samples. • Can analyze multiple samples simultaneously. • Typically looking for a specific compound or class of compound per test. • Cost: $$ • Time: 1 hr / analysis (+ sample preparation)	 	• Cross-reactivities with other compounds may not be well understood. • Some systems use fixed panels, which prohibits screening of novel compounds. • Reported inconsistencies across platforms.[82]

Gas Chromatography Mass Spectrometry (GC-MS) [78, 83]	• Typically laboratory based, though some portable systems exist. • Ability to separate compounds based on chemical properties. • Separation of compounds enables identification of individual components. • Extensive spectral libraries. • Some tools available for unknown classification. • Cost: $$$ • Time: 10 min – 45 min / analysis (+ sample preparation).	 	• Ability to differentiate isomers can be challenging at times. • Some compounds may require chemical derivatization for accurate detection. • Many systems use helium gas, which is increasingly expensive and challenging to obtain. • Systems can be converted to hydrogen gas, but limited resources (*i.e.*, libraries) exist.
Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS) [78, 83]	• Laboratory based system. • Ability to separate compounds based on chemical properties. • Separation of compounds enables identification of individual components. • Excellent for quantitative analyses of bulk and trace level compounds. • Cost: $$$$ • Time: 10 min – 45 min / analysis (+ sample preparation).	 	• Requires use of toxic solvents. • High maintenance costs. • Quantitative analyses may be time consuming and difficult. • Sample preparation is typically lengthy.
Liquid Chromatography High-Resolution Mass Spectrometry (LC-HRMS) [84–86]	• Laboratory based system. • Ability to separate compounds based on chemical properties. • Separation of compounds enables identification of individual components. • Excellent for trace non-targeted analysis and identification of unknowns. • Some tools available for unknown classification / identification. • Cost: $$$$ / $$$$$ • Time: 10 min – 45 min / analysis (+ sample preparation).	 	• Requires use of toxic solvents. • High maintenance costs. • Rich data can be challenging to interpret and process. • Data storage can be problematic due to large datafiles. • Sample preparation is typically lengthy.

Note: This table is not exhaustive. It is only meant to illustrate commonly used analytical tools in various communities.

Determining the technique, or combination of techniques, to use is left up to the individual or defined by policy within a laboratory or agency. In communities such as customs and border interdiction, the available techniques are largely driven by bulk procurements based on evaluation of techniques by laboratory personnel. The forensic seized drug analysis community, however, has a non-governmental body that provides overarching guidelines on the types of techniques that can be used (in this case, the SWGDRUG guidelines) but does not prescribe specific instrumentation or types of samples where specific techniques must be used. On the other extreme, public health drug checking has little to no available guidance on what type of techniques should be used.

For many of these techniques, there is a degree of subsampling and/or sample preparation that is required prior to analysis. This may be as simple as diluting a small amount of powder into a

solvent for qualitative analysis by GC-MS or as complex as a multi-step, time-intensive extraction protocol to prepare toxicological samples in complex matrices.

It is important to note that guidelines for confirmatory analysis typically require a sample to be tested using more than one analytical tool. In forensic seized drug analysis, SWGDRUG guidelines explicitly state that a minimum of two analytical techniques must be used [87]. A multi-technique approach is seeing increased adoption in screening environments as well. One example is drug checking for public health, where there is growing reliance on the combination of test strips and fieldable FTIR techniques to overcome FTIR's poor sensitivity for trace fentanyl detection [88].

4.2.2. Challenges

Analytical challenges faced by the drug detection and analysis community mirror the broader detection challenges in analytical chemistry. Most highlighted communities stated increased specificity of analytical techniques as a major need. Communities that deal with complex street-level drugs and/or toxicological samples also highlighted the need for increased sensitivity coupled with the ability to detect both major and trace components within a sample. For personnel who are not analytically trained and/or work in the field, the desire for more intuitive interfaces and workflows was a consistent theme. For those who interact with complex samples and matrices, not knowing what sample preparation would be best presented a challenge. Lengthy sample preparation protocols as well as protocols that require the use of toxic chemicals represented additional challenges, especially for personnel working in a mobile or forward operating laboratory environment where access to solvents, glassware, and consumables may be limited. The need for guidance on how to develop analytical schemes and how to know when sufficient sample analysis has been completed was also voiced.

Another avenue of identified challenges focused on difficulties with implementation of new techniques and verification of emerging technologies. Every community highlighted the concern that there are limited resources available to assist agencies and laboratories with implementation and validation of new techniques, which makes adoption of new tools difficult. In forensic laboratories, validation of new techniques can take years to accomplish and often require laboratories to figure out their validation plans on their own. These struggles are compounded by procurement challenges which often require agencies to either plan for new technology well in advance or make immediate purchasing decisions with limited to no actionable information.

A specific challenge that was echoed by public health, law enforcement, first responders, and policymakers was the lack of quality control surrounding some of the one-time-use screening tools. Batch-to-batch variability presents challenges for the interpretation of results. Test strip variability within a manufacturer was highlighted as a key example here. Changes in the antibody used or the quantity of the antibody used are not communicated to the end-user. Test strip results changing with each batch of strips used was highlighted as a challenge for communicating results and potential dangers to the community.

Several other analysis challenges focused on the need for increasing staffing, rising equipment costs, and cost prohibitive third-party testing as major drivers for increased backlogs and decreased timeliness of the data. The need for rapid, cost-effective, and comprehensive analyses was a common challenge shared across all communities.

4.2.3. Opportunities

The most obvious area for opportunity within sample analysis is the development of new technologies, or modifications of existing technologies, to address the challenges and limitations of currently used techniques. As part of the workshop, participants were asked to provide a wish list of characteristics that an "ideal" technology would have. Characteristics that were listed multiple times are shown in the callout box in this section. It is important to note that some of these characteristics relate only to field-deployed screening technologies.

Callout Box 2. Characteristics of an Ideal Technology

Question

Workshop participants were asked, "What are the characteristics of an ideal drug analysis technology?".

Responses

- Easy to transport
- Near-instantaneous results
- Easily interpretable data
- Cloud-based library updates
- Intuitive operation
- Ability to link with reachback services
- Low resource consumption
- Low upfront cost
- Ability to identify analogs
- Ability to analyze mixtures
- Report customization
- Interoperability with other types of instruments

Development of new technologies is ever evolving, and there are emerging analytical tools that may be able to address some of the challenges faced by existing techniques. A series of white papers recently released by the Forensic Technology Center of Excellence[89] highlights some emerging techniques for the forensic seized drug space. Similarly, the Rapid Technology Assessment program[90] within CBP looks at new and emerging technologies for screening samples in the field. **Table 2** provides information on some emerging analytical tools that may be of interest to the different communities for screening or confirmatory analysis of drug material, paraphernalia, and/or biological specimens.

Table 2. Types, characteristics, and potential limitations of emerging technologies for drug analysis.

Technology	Characteristics & Potential Limitations	Sample Types
Screening Techniques		
Surface Enhanced Raman Spectroscopy (SERS) [91–94]	• Overcomes low sensitivity of Raman spectroscopy. • Demonstrates capability to analyze drugs in pure form, mixtures, and within toxicology matrices. • Could be coupled to electrochemical or microfluidic devices for enhanced capabilities. • Requires some level of in-field sample preparation.	
Near Infrared Spectroscopy (Near-IR) [95, 96]	• Similar to FTIR, but with a spectral range of 14,000 cm^{-1} to 4,000 cm^{-1}.[97] • Systems come in a variety of compact, easy to transport, form factors. • Samples may be analyzed in native packaging.	

	• Near-IR may be less sensitive than other spectroscopy techniques, making detection of minor components difficult.	
Ion Mobility Spectrometry (IMS) [98–100]	• Commonly employed for trace explosives detection, IMS enables separation of compounds without vacuum systems. • Limited libraries on commercially available systems. • Possible false positives from benign chemicals or incorrect identification of drug due to library limitations. • High sensitivity is good for trace applications but may present challenges for bulk analysis.	
Confirmatory Techniques		
Gas Chromatography Infrared Spectroscopy (GC-IR) [101–104]	• Combines discriminatory power of IR spectroscopy with separation capabilities of GC. • Systems come in two configurations – vapor phase detection or desorption. • Can be coupled with a MS detector for GC-IR-MS analysis. • Requires significantly more material than GC-MS due to lower sensitivity. • Requires cryogenics.	
Gas Chromatography Vacuum Ultraviolet Spectroscopy (GC-VUV) [105–108]	• Similar to GC-IR but uses VUV as the spectroscopic detection technique. • Can be coupled with an MS detection for GC-VUV-MS analysis. • Analyses can be coupled using hydrogen as the carrier gas. • Limited real-world demonstration of technique in practicing laboratories.	
Benchtop nuclear magnetic resonance spectroscopy (NMR) [109–111]	• Low field NMR systems that do not require cryogenics. • Lower sensitivity and resolution than high field systems, leading to potential challenges with mixture analysis. • Structural elucidation of unknowns is more challenging on low field systems. • Potential to complete quantitative analyses. • Development of flow-through benchtop NMR systems may enable LC-NMR analyses.	
Liquid Chromatography Ion Mobility Mass Spectrometry (LC-IMS-MS) [112–114]	• Adds another dimensionality (ion mobility) to already rich high-resolution LC-MS data. • Added dimensionality can assist in compound identification and discrimination. • Data interpretation can be difficult without specific training. • High upfront costs.	

Note: This table is not exhaustive. It is only meant to illustrate some of the potential future analytical tools for drug detection and analysis.

The development of new analytical techniques alone will not sufficiently address the challenges identified in this section. Approaches to simplify technique adoption, validation, and implementation also need to be considered. Several were discussed by workshop participants, including the consolidation of foundational validation efforts to a select number of research laboratories that are not engaged in routine analysis of samples and have the bandwidth to complete these time consuming, data-intensive studies. From there, validation/verification and implementation packages could be created and provided to the community, similar to what NIST has begun to do for new technologies in the forensic drug analysis space[115]. This could be coupled with the development of consensus-based standard methods that are mandated for to use. Cohesive use of uniform analytical methods within a field will not only simplify analysis but also greatly increase the ability to aggregate data for other applications.

An additional opportunity that was posed was the development of a center where personnel from these communities could gain hands-on experience with new technologies prior to agencies making financial investments on technologies that may or may not be fit for purpose. This type of center could allow personnel to work with new technologies on relevant and realistic samples in operational environments that mimic what they would encounter in their day to day. It could also act as a teaching center, providing training above and beyond what is provided by vendors. This approach would also benefit industry as it would provider feedback from the community on the strengths of new technologies as well as areas that need to be improved.

Another opportunity, which has been highlighted elsewhere[108], is to lower the barrier between development of new technology in academia and deployment of that technology into the field. This can be accomplished through multiple mechanisms, including requiring – as part of grants or funding opportunities – researchers to work in the field with collaborators on technology development to ensure the solution is fit for purpose. Funding agencies providing mechanisms to support the technology development pipeline beyond the initial research and development stage will also help get these new technologies into the hands of end-users more rapidly.

Callout Box 3. Major Challenges and Opportunities in Sample Analysis.

Challenges

- Need for increased specificity and sensitivity, especially in complex samples.
- Lack of sample preparation best practices.
- Lack of validation and implementation resources.
- Discrepancy between vendor claims and real-world instrument performance.
- Batch-to-batch variability of single-use tests.

Opportunities

- Incentivize researchers to work directly with stakeholders on new technology development.
- Simplify validation and verification procedures.
- Develop consensus-based standards for instrument and sample preparation procedures.
- Create a center where stakeholders can get hands on experience with technology before purchasing.

4.3. Data Interpretation

4.3.1. Current Status

Data interpretation can vary widely based on the technology and particular question being addressed. The simplest form of data interpretation is considering red light / green light results from screening techniques. In these scenarios, a backend spectral library and search algorithm automatically process collected datafiles. This system alerts the end user to the presence (red light) or absence (green light) of a compound of concern. Other types of data interpretation for screening tools involve observing color changes in chemical reactions or identifying the presence or absence of bands on test strips (analogous to interpreting a COVID-19 test). There are a few scenarios, mainly in the customs and border interdiction space, where end-users can send spectral data to a remote reachback center where technical staff can provide deeper analysis and interpretation.

Data interpretation for analytical instruments that do not use the red light / green light approach require comparison of collected data to spectral databases that are either generated

in-house, are publicly available, or are vendor-provided. In these instances, trained personnel use search algorithms (vendor provided or publicly available) to compare the reference spectra to the measured spectrum to determine the presence or absence of compounds. For chromatographic-based techniques, there is an additional dimensionality to the data that typically requires running physical standards concurrently with samples to compare retention time values. Most laboratories have self-defined metrics for determining when a compound is reportable[116, 117] and there are consensus-based standards available for communities[118–120]. For laboratory based testing, there is typically a multi-level review process that must be followed to ensure the reported results are correct[121].

Upon encountering unknown compounds, additional algorithms and software tools can be utilized to not only compare reference and unknown spectra but also to determine the compound's class or specific chemical makeup. Many of these tools require advanced training and manual data manipulation and thus are often only used in laboratory settings. It should also be noted that data interpretation can involve combining results from more than one analytical technique to determine the presence of absence of a compound.

4.3.2. Challenges

Two primary challenges that were repeatedly voiced by workshop participants were the demand for increased standardization – including physical standards, reference data, and documentary standards – and the requirement for advanced tools to detect and classify unknown compounds. Since nearly all the analytical instruments used in drug analysis rely on spectral libraries for comparison, the need for timely, high-quality reference data is critical. However, the pace at which spectral libraries are currently updated is often insufficient to keep up with introduction of new drugs into the supply. It is possible for new drugs to go unreported for weeks to months because of the lack of reference spectra – especially in instances where the readout is simplified to a red light / green light. In the customs and forensic spaces, agencies often generate their own reference data from commercially available chemical standards. These standards can be expensive (hundreds of dollars per milligram) and there are instances where the availability of these standards lag relative to the emergence of a new drug.

In addition to reference and physical standards, there is a need for additional documentary standards to assist personnel, mainly in laboratory environments, establishing uniform protocols for when compounds are reportable. As will be discussed in **Section 5.2.3**, having a uniform reporting protocol would significantly impact data aggregation efforts and allow for stronger conclusions from the data. A more specific need is the desire for more guidance and uniform practices surrounding whether a new compound is an analog of a scheduled compound. This type of question is important from the customs, law enforcement, and forensic science perspectives[108, 122]. Even though model analogue laws exist[123], state laws differ and personnel in these communities noted that they often do not know when something should or should not be considered an analog.

The second major challenge discussed was how to handle the detection, and subsequent classification or identification, of unknown compounds that may be of concern. Since many techniques rely on spectral libraries if a compound is not present in the library – or at least not

spectrally similar to other compounds in the library – it may go unnoticed. While this can be an issue for all analytical techniques, it is more problematic for those that do not contain a chromatography component (the separation of individual compounds can simplify detection). Even if a new compound can be detected, few agencies have the necessary tools or expertise to classify or identify what the compound is. There are a limited number of software tools available to assist in this task but were noted as either being proprietary or not user-friendly. Due to limited expertise, the classification / identification component is often completed by a select handful of laboratories who have expertise in structural elucidation. If the sample is relatively pure, the physical material can be sent for additional testing using techniques like NMR for definitive identification. Otherwise, the use of existing spectral data to determine a "best guess" is often all that can be done until physical standards are available for comparison.

Two other universal challenges that were highlighted included the lack of data interoperability across instruments from different vendors and the need for better guidance on what to do when a user obtains an inconclusive result. File formatting differences between, and even within, vendors presented challenges with sharing data across agencies and even comparing data within a laboratory.

Other challenges that were highlighted were more specific to one, or several communities. These included the need for increased reachback services (mainly in communities where in-field screening is completed), the need for understanding – in plain language – challenges in cross-reactivity (what unrelated compounds could elicit a positive result) and/or false positives for field testing, and partial result reporting in confirmatory testing that is panel-based (post-mortem toxicology and clinical testing).

4.3.3. Opportunities

Identified opportunities for addressing challenges in data interpretation largely surround increased efforts to develop standards (physical, reference, and documentary) and software. While there are several efforts to increase the pace at which reference data is provided to the community[15, 124–127], the frequency of updates could be increased. One challenge with existing, freely available, databases is that they are largely GC-MS focused. This is of benefit for laboratories, where this technique is commonly employed, but is not useful for in-field techniques such as FTIR and Raman spectroscopy. One potential opportunity for high impact would be a centralized location where reference data is collected and curated for multiple types of instrumentation including GC-MS, FTIR, Raman, and LC-HRMS. This effort would need to be nimble, and work alongside chemical standard suppliers and practicing laboratories to ensure data is being disseminated as quickly as possible, without sacrificing quality. Ideally, this effort would be funded in a manner that allows dissemination of reference data to those who need it free of charge, in vendor agnostic formats.

Addressing the reference material issue is more nuanced due to the high costs and time required to synthesize new compounds. Some efforts, such as the DEA Special Testing and Research Laboratory or the REMEDY project[128] provide forensic laboratories with access to no-cost reference materials, but their scope and reach are limited. CDC has also provided some resources in this space, with the development of the traceable opioid material kits[129] that are

distributed to those with a need, free-of-charge. This model could be expanded to other drug classes and continually evolving opioid threats, as it has been demonstrated to be extremely helpful[130].

An alternative to the widespread need for reference materials would be the standardization of instrument methods and centralization of database construction efforts. An example of this type of approach can be found within CBP where the INTERDICT science center generates reference spectra for all field-deployed Gemini systems. Collection and curation from reference standards is centralized, and updated libraries are pushed out to the field. Similar efforts could be undertaken for public health, law enforcement, and forensic testing.

The need for increased documentary standards will likely require years to address due to the slow process of consensus-based standards. Efforts for standards development within forensic science have been ongoing for the last decade through the OSAC program[131], which is administered by NIST. Through this program, practitioners, researchers, statisticians, and legal representatives work to develop consensus-based standards for forensic testing, reporting, evidence handling, and other related processes. OSAC's 22 subcommittees include areas focused on seized drug, toxicology, and medicolegal death investigation. As of May 2024, OSAC has seven seized drug standards and 13 toxicology standards on the registry. An analogous organized effort does not currently exist within other communities, though they would likely benefit from such efforts to standardize the fields. This type of organization could be supported by federal government agencies with vested interest. It should be noted that many of the standards that come from OSAC that are method-focused do not prescribe specific parameters, but instead provide general frameworks.

Though centralized efforts for standards development do not exist outside of the clinical toxicology, forensic science, and medical examiner and coroner spaces, there are a handful of standards that could serve as starting points for future endeavors. A DHS-led effort to develop standards for trace detection of opioids in the field provides a foundation for ventures in the customs and law enforcement settings[132–134].

Beyond standards, the development of new algorithms for compound detection, classification, and identification are necessary to increase objectivity in data interpretation and enable ways to glean additional insights from the data. While academia has developed and proposed algorithms for a range of technologies[10, 11, 135–142], one issue often faced is access to real-world samples and validation data. Development of a repository of well-characterized, real-world samples and spectral data to use for validation of new analytical approaches or algorithms would be beneficial to address this need. A needs document from the communities that outlines specific requirements for new algorithms would also help guide research funding efforts to ensure applicability to the end-user.

Another way to simplify data interpretation efforts would be to increase the amount of application-specific training that is available to end-users. A recurring theme in the workshop was that vendor training often lacks specificity for users within this community. Participants expressed frustration with high-level, generic training that doesn't address the nuances of real-world applications or provide guidance on interpreting typical sample data. The development of a training institute focused on the needs of this community would be of value. The need to

develop training not only focused on sample analysis and data interpretation but also reporting, method development, method validation, and how to handle questionable data was highlighted. Specialized training for tools to elucidate unknown compounds would also be helpful.

In addition to training, the implementation of quality assurance and quality control programs in many of these spaces would be advantageous. Forensic chemists must complete proficiency testing as part of their accreditation[143], and similar types of testing could be implemented in other scenarios as well. Proficiency testing and/or interlaboratory studies would help identify data interpretation gaps within a community and present opportunities to bring personnel closer to uniform reporting. An alternative approach, especially for those using screening tools in the field, would be to mimic the training and ongoing QC of end-users through confirmatory laboratory testing of a subset of samples. New York State Department of Health is currently taking this approach for FTIR analysis in drug checking settings – comparing results obtained by FTIR operators to those from confirmatory laboratory testing.

Callout Box 4. Major Challenges and Opportunities in Data Interpretation.

Challenges

- Lack of reference standards and data.
- Lack of data interpretation standards and protocols.
- Differentiating structurally similar compounds.
- Poor understanding of method limitations.
- Data interoperability issues.
- Difficulty in determining if an important unknown compound is present.

Opportunities

- Increase standards efforts.
- Stand up a centralized, open access, reference data collection and dissemination effort.
- Develop new algorithms to increase the objectivity and simplicity of data interpretation.
- Create new approaches for unknown identification.
- Develop training and QA/QC programs.

5. Current Status, Challenges, & Opportunities – Data

Though every community represented at the workshop was responsible for acting on drug data, the nature of the action fell into two categories. The first is immediate action, which is defined as the action someone takes on a single result or piece of data. An example of immediate action might be a police officer conducting a field test of a powder at a traffic stop. Given a single piece of data (the result of the field test), the officer must decide if they will be making an arrest. It is important to note that not all immediate actions are taken as soon as a result is obtained. In the case of post-mortem toxicology examination, where a report is generated that lists the drugs and their concentrations found in a biological matrix, the immediate action is to determine if the drugs are the cause of death. The issuance of a death certificate can take weeks to months but is reliant on that analysis.

The second type of action involves compiling multiple pieces of data, often from multiple sources, to be used for dissemination and/or decision making. Examples of cumulative data aggregation include public health alerts that inform a community of the prevalence of a new drug, using fatal overdose data to determine if a new naloxone distribution policy is effective, or identifying trends in the movement of illicit drugs within a geographical region over time. Collating this type of data often requires merging multiple data streams, containing both chemical and non-chemical data. These efforts also often require statistical processing of the data to identify trends or calculate summary statistics.

Callout Box 5. Comprehensive Drug Data.

Question	Responses	
Workshop participants were asked, "What elements would comprehensive drug data contain?".	• Comprehensive Chemical Analysis • Qualitative & Quantitative Data • Weight of Sample • Color Measurement • Sample Form (Powder, Pill, etc.) • Identification of Synthesis Markers	• Date of Sample Encounter • Location of Sample Encounter • Expected Sample Contents • Photograph of Sample / Markings • 3-D Imaging of Pills • Package Markings (i.e. Stamps)

A stark reality of this type of data aggregation is that the data being received from different sources does not contain the same information fields or is reported in different formats, which can create challenges in merging datasets and interpreting results. During the workshop, participants were asked what a “complete” drug dataset would look like to help frame discussions around standardizing data. The categories that attendees felt needed to be captured for a complete dataset are highlighted in the callout box.

The following sections will cover the current status, challenges, and opportunities for taking immediate action on a piece of data, aggregating data, and collating / disseminating data.

5.1. Immediate Action

5.1.1. Current Status

Immediate action refers to what is done with results from a single sample, individual, or analytical measurement. Depending on the community, the nature of this action can vary widely. Examples of actions taken by different communities are highlighted in the graphic within this section. While many of these actions will end the analysis and data reporting chain, there are instances where an immediate action will necessitate another analysis, generate another piece of data, and require a subsequent action to be taken. An example of this is a law enforcement officer making an arrest based on a positive field test. The positive field test results in an arrest (immediate action) and results in the drug evidence to be sent to a forensic laboratory for additional analysis. Once completed, the forensic result will be used in the trial of the person who was arrested.

There are two key, and often interconnected, questions that are inherent to determining what analysis to complete and whether or not to take action with the result: 1) how quickly is the answer needed and 2) how much confidence is needed to take action on the result. Going back to the law enforcement example, a first immediate action is to determine if someone should be arrested for possession of drugs. In this instance an answer is needed quickly – meaning the results of the screening technique determine the action taken. This reliance requires a high confidence in the reporting of a correct result. A technique that has the lowest false positive rate would be preferred, since the ramifications of incorrectly apprehending someone outweigh the risk of not doing so. Conversely, in a harm reduction setting where PWUD are provided with information on what is in their sample, the analyst is likely more comfortable with false positives than false negatives – the risk of telling someone fentanyl is present in their sample when there may not be is much lower than the inverse. In the harm reduction example, taking immediate action on a result with slightly lower confidence may be acceptable.

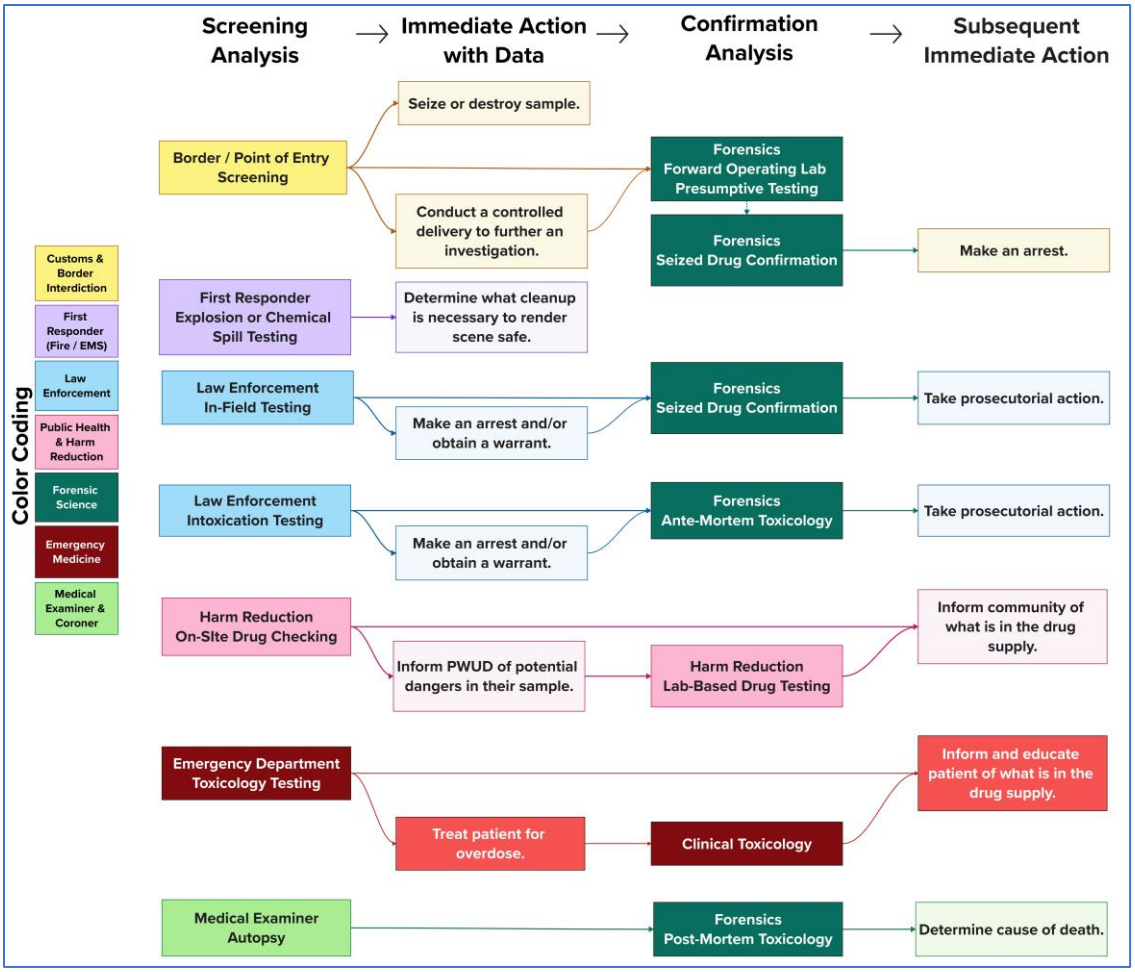


Figure 7. Flowchart depicting types of immediate action taken by communities involved in drug analysis.

5.1.2. Challenges

Challenges that were brought up by community members that prohibited or diminished the ability to take immediate action on data largely focused on incomplete data, lack of timely data, and shortages in staffing or resources.

Having to make decisions with incomplete data was a challenge that was echoed across communities and across those acting on results from both screening and confirmatory analyses. A common challenge in law enforcement and customs communities trying to act on results from screening analyses was the difficulty, or inability, to decipher whether a detected compound was controlled, uncontrolled, or an analog of a controlled substance. In these scenarios, the need for the up-to-date schedule or legal status of a compound to be coupled with the analytical result was highlighted. Within the public health and drug checking realm, challenges with analytical tools being unable to detect low-level, potent compounds meant acting on inconclusive data was at times difficult. A specific example of this challenge is determining what to do with a result that indicates the presence of a cutting agent or diluent, but not fentanyl.

Challenges of incomplete data from confirmatory analyses were highlighted by the forensic science and medical examiner communities, where narrowing testing panels may not provide a complete information into what drug(s) a person consumed[144, 145]. Narrow testing panels can also complicate interpretation of quantitative results, especially relating to the determination of accidental versus intentional exposure. Similarly, forensic laboratories may stop testing once a controlled substance is detected – leading to incomplete understandings of the chemical composition of samples.

Receiving data in a timely manner to act was a challenge echoed by nearly every community, from both the immediate action standpoint and the larger collation and dissemination efforts discussed in Section 5.3. This challenge was most acutely summed up in the emergency medicine community, where the time required for clinical toxicology testing may be longer than the time a person is in the hospital – meaning the patient may never be informed about what drug(s) they consumed. In some forensic laboratories, where backlogs are acutely problematic[6], testing may not be completed in time for court dates, presenting challenges in prosecution of defendants. The lack of comprehensive detection techniques for drug checking in the field in a harm reduction setting means that samples sent to laboratories for confirmatory testing will have already been used before the submitter receives a result.

5.1.3. Opportunities

Opportunities to address these challenges range from simple updates to how data is displayed on an instrument to development of next generation analytical advancements to increased staffing within communities. Data readouts, such as displaying whether a substance is controlled, is one example of a simple solution that could have a significant impact on one or more communities. However, given the changing drug landscape and continual scheduling of new compounds, instruments would need to be able to connect to the cloud and receive real-time, over-the-air updates, to make this truly actionable. The ability to push updates remotely to instrumentation would also help improve access to reference libraries and reference data, a challenge highlighted in the previous section. This, of course, needs to be balanced with IT security concerns of agencies.

Another key opportunity to make a significant impact on multiple communities is to expand toxicology testing panels. This opportunity is less of an analytical challenge – modern toxicology instrumentation can detect a wide range of compounds at biologically relevant concentrations – and more a policy, legislative, and funding challenge. To have the greatest impact, an approach where testing panels are dynamic and informed by drug trends in geographical areas where samples are collected is needed. Some initial efforts to recommend dynamic testing scopes have been started by NPS Discovery[126]. Realizing the true benefit of this approach, however, would require test panels to be consensus driven and mandatory.

Further development of some of the emerging analytical tools discussed in Section 4.2.3 could help address data timeliness and incomplete data challenges. Development of tools capable of providing low-cost, comprehensive, on-site analysis are needed to overcome this challenge. For those conducting confirmatory testing, funding for increased staffing and instrumentation to decrease backlogs and shortages could further help reduce time lags and address issues for

both immediate action and data collation. Staffing shortages are pronounced in the medical examiner community, as highlighted by the National Association of Medical Examiners[146, 147]. In the absence of increased resources, laboratories could consider alternative approaches to remedy backlogs, such as rethinking analytical workflows and data review approaches to decrease time requirements or improve turnaround time. Some initial studies have demonstrated that implementing new technologies or analytical methods can significantly decrease the analytical time required for casework[9, 148]. Standardization of methods across laboratories could also assist in reducing the time required to review casework, or all cases to be reviewed by practitioners in other labs where a backlog may not be as problematic. The use of artificial intelligence or machine learning to assist in data workup or review could also prove useful in reducing turnaround times. Models could also be developed to determine how to best triage cases to increase throughput for those with upcoming court dates. Agreements between laboratories to transfer cases could also help unburden those laboratories which are facing the highest backlogs.

Callout Box 6. Major Challenges and Opportunities in Immediate Action.

Challenges	Opportunities
• Incomplete data due to instrument or testing limitations creates blind spots. • The time for sample analysis and data interpretation prohibits the ability to take immediate action. • Staffing, technology, and resource constraints.	• Modify how results are displayed on instruments to include actionable metadata. • Expand toxicology testing panels to reflect current trends. • Expand comprehensiveness of forensic reporting. • Increase use of machine learning for data analysis. • Rethink workflows and distribution of cases.

5.2. Data Aggregation

5.2.1. Current Status

Aggregation of data occurs at different levels within communities and may also require accessing and assessing data from other communities. Combining data often encompasses merging chemical data with meta-data (date and location sample was encountered, weight of sample, sample packaging characteristics, etc.). For chemical data, aggregation typically focuses on processed data (reports, spreadsheets, etc.) rather than raw datafiles.

Data aggregation unlocks the ability to gain insights about the drug supply that would not be possible by looking at any one datapoint. Aggregation allows for things like trend analysis to highlight changes in the drug supply over time, datamining to determine if a new compound was in the supply prior to its discovery, and forecasting to determine when a shift in the drug supply may occur based on previous information. This type of data is also crucial to understand the efficacy of policy changes, intervention efforts, and enforcement efforts in reducing the supply of drugs, or the harm that the drugs are causing.

Aggregation efforts may take place at a site level all the way through to the national level. In the simplest case, an individual needle exchange site may aggregate drug checking information they obtain to inform their community on trends in the supply. On a more complex side, a

HIDTA or a state fusion center may be combining fatal and non-fatal overdose data with naloxone distribution data, law enforcement screening data, and forensic seized drug and toxicology data to identify geographical hotspots where overdose outbreaks may occur. There are also national level aggregation efforts such as the National Forensic Laboratory Information System (NFLIS)[5] and State Unintentional Overdose Reporting System (SUDORS)[37] which aggregate forensic laboratory testing data and medical examiner, coroner data, respectively. Academic entities and partnerships, such as the Emergency Department Drug Surveillance project[149] and the Massachusetts Drug Supply Data Stream[150] also have concerted efforts on data aggregation from multiple data sources.

5.2.2. Challenges

There are several key challenges and barriers to data aggregation that were brought up by workshop attendees which have been broken down into four overarching categories.

1. Differences in Data Structure – This is, perhaps, the most straightforward and obvious challenge related to data aggregation. Given the wide range of analyses being conducted and the differing missions of communities, the type, quality, and format of data that is being generated varies significantly. Simply getting a dataset into a shareable format can be difficult for a variety of reasons. Results from screening analyses (*i.e.*, on-site drug checking) may never be captured in a central repository or may only be captured in a non-electronic format. For laboratories conducting confirmatory testing, the laboratory information management system (LIMS) may not export data in a form that is useful or easy to manipulate. Differences in data structure are further complicated by the lack of a standard set of variables and nomenclature to collect for drug data, which means that identifying similar fields across datasets can be difficult.

Reporting chemical results can also lead to difficulties and confusion since compounds often have multiple different names. For instance, a synthetic cathinone that is commonly reported as butylone could also be reported as bk-MBDB, β-keto MBDB, or its formal name 1-(1,3-benzodioxol-5-yl)-2-(methylamino)-1-butanone. Depending on reporting practices and limitations of the analytical techniques, the exact drug may not be explicitly identified – instead being listed as an isomer group such as “butylone or an isomer thereof” or “eutylone or an isomer”. Similar issues exist in reporting or positional isomers as well. A compound such as *para*-fluorofentanyl may also be reported as “*p*-fluorofentanyl”, “*para*-fluorofentanyl or an isomer”, “an isomer or fluorofentanyl”, or, simply, “fluorofentanyl”. The latter two names do not provide discrimination of *para*-fluorofentanyl from the *ortho*- or *meta*- isomers of the compound. Even simple naming differences, such as whether the salt form of a compound is listed (methamphetamine or methamphetamine HCl), can cause difficulties.

Merging of chemical data with related and unrelated non-chemical drug data can also be challenging, especially if agencies do not have dedicated staff with specialized skills in data science, statistics, or epidemiology.

2. Data Sharing and Ownership – Non-technical barriers often arise around data sharing and data ownership. While sharing data within a community (such as sharing forensic case information within a laboratory system) can be relatively easy, sharing across communities can

present greater challenges. Sensitivity of the data must be considered, especially as it relates to sharing information that may be considered PII, HIPPA protected, or law enforcement sensitive. Stripping datasets to maintain confidentiality while still being useful is critical but can be time consuming, especially for agencies that are resource limited.

Data ownership is another key consideration that can lead to issues with sharing data for aggregation. If an independent laboratory is doing drug product testing for a needle exchange site that is funded by a state health department, the question arises of who owns the resulting data. Data management agreements are key to outlining who owns the data and what can, or cannot, be done with the data. Implementing these data management agreements, however, is often time-consuming and requires the involvement of legal counsel on all sides.

3. Limitations in the Data – It is critical to understand the limitations of the data being aggregated to ensure accurate conclusions and inferences are being drawn. Part of this is understanding the scope of testing and reporting that is being completed. For instance, the scope of forensic drug laboratories is to identify what controlled substances are present in a sample for prosecutorial purposes. Because of this scope, many laboratories only report controlled substances and do not report cutting agents, diluents, adulterants, etc. If this scope is not understood, the data could be misinterpreted. An example would be using forensic laboratory data to understand the prevalence of xylazine in a geographical region. Many laboratories do not report when xylazine is in a sample because it is not a controlled substance.

Even when the scope is understood, limitations in the data can arise from differences in reporting policies. A real-world example of this impact is the NFLIS dataset[5], which is an aggregated dataset of the majority of forensic drug testing completed in the country. Because laboratories are allowed to submit results based on their own reporting policy, an identical sample may be reported differently to NFLIS. If a sample were to contain heroin (a Schedule I compound), fentanyl (a Schedule II) compound, and xylazine (an unscheduled compound), a laboratory could 1) report all three compounds, 2) report heroin and fentanyl (if the policy is to report only controlled substances), or 3) report heroin (if the policy is to only report the compound with the highest schedule). These reporting differences, compounded with differences in the analytical techniques and methods used for analysis, present major challenges drawing trends and interpreting aggregated results.

Along with data reporting differences, it is important to understand the quality of the data being collected / reported, which can be a function of both the analytical technique being used and the way it is being implemented. For instance, reporting fentanyl from a positive fentanyl test strip result does not have the same accuracy or specificity associated with it as reporting fentanyl from a GC-MS analysis. Where, and how, that GC-MS result is obtained is also nuanced, however. A GC-MS result obtained from a confirmatory test at an accredited forensic laboratory will be of higher quality than a GC-MS result obtained from a portable system run in the field. It is also important to understand data stratification. Looking at an average purity of drug, such as methamphetamine may be misleading if that purity is obtained by averaging purity of powder samples (high purity) and pill samples (low purity).

It should also be noted that a significant amount of data, regardless of the community, is still entered manually. This method can lead to clerical errors or present aggregation challenges

when open text fields are used. The rate at which data becomes available for aggregation – due to backlogs, embargo periods, etc. – may present challenges combining multiple datasets in a meaningful, and timely, way. Additionally, datasets are not always static. Handling dynamic datasets, such as laboratories reporting a preliminary result and then updating it with a final or amended result, can be difficult.

Another key challenge highlighted during the workshop focused on how policy changes can reflect data changes. For instance, when a new drug is first identified in the supply it is likely not scheduled, meaning many forensic laboratories may not report the presence of the compound on reports. Once it is scheduled, laboratories will move to report its presence. This can lead to what would look like an immediate emergence of a new drug into the market when, if fact, that compound may have been present for many months. Forensic testing policies may also shift in terms of specificity. A laboratory may switch from determining the optical isomer of a drug like methamphetamine to just reporting methamphetamine, leading to differences in how those results will be entered into their LIMS system.

4. Tools & Goals of Aggregation – Understanding the purpose for aggregating data is critical to identify what tools, and datasets are required. Unclear goals for data aggregation can lead to confusion as to what tools and datasets are required and an understanding of whether the required datasets contain the necessary data fields.

With the increase in the volume of data that is being produced, it is becoming increasingly challenging to examine datasets manually or with simple data processing tools. The rise of AI and ML presents new opportunities to gain insights from large datasets, but little has been done to identify the best approaches and tools for this or to standardize how this could be done at scale. The limitations and ethical concerns of these approaches also need to be better understood.

5.2.3. Opportunities

Addressing many of the challenges and barriers surrounding differences in data structure, data sharing, and data ownership could be addressed through the development of consensus-based standards, best practices, and model templates. Perhaps most impactful would be the development of a set of possible data fields, and standardized nomenclature for those fields, that capture the needs of as many communities as possible. This harmonization would simplify merging discrete datasets while also increasing transparency and understanding of what a dataset does and does not contain. Along with this, defining the minimum necessary data that should be collected would also be beneficial. One such effort, by the HL7 International – Public Health Work Group, could serve as a blueprint for such an endeavor [151].

Standardization of naming within and across communities would also address some of the challenges with data aggregation. Efforts to agree on naming of individual compounds as well as naming of groups of compounds (*i.e.*, positional isomers or structural isomers) is required.

Lowering the barriers of data sharing could also be accomplished with the development of best practices for data de-identification or data scrubbing. Understanding what data fields are PII, HIPPA, or law enforcement sensitive, and whether they need to be removed or modified prior

to sharing is necessary. Best practices for responsible data use are also needed. These could be coupled with model data use and data sharing agreements that agencies could adopt and adapt, which may also streamline and simplify data sharing efforts.

To address challenges presented by limitations within the data requires increased transparency of how the data was generated, the analytical methods used to generate the data, and the reporting policies of the agency generating the data. This could be accomplished through several mechanisms. Aggregating agencies could require that submitting agencies complete a questionnaire designed to capture limitations and convey those limitations when aggregate data is disseminated. Community-wide surveys could be conducted to establish the landscape of the field and the associated limitations. Consensus-based guidance on how to convey data limitations could also be drafted for each community.

The need for technological advances to address the challenges with immediate action also presents an opportunity to advance data aggregation. Internet-connected analytical tools could speed up the creation of datasets by sending results directly to aggregating agencies, removing the need for manual data entry, and opening the possibility and collate chemical and non-chemical data in real time. Advances in AI and ML could also streamline data aggregation efforts, both in terms of merging and combining datasets as well as extracting insights and information for the aggregate data. These approaches could also enable strong predictive analytics capabilities – potentially opening new opportunities such as forecasting and preemptive deployment of resources.

Callout Box 7. Major Challenges and Opportunities in Data Aggregation.

Challenges	Opportunities
• Differences in data structures and drug naming can make merging datasets difficult. • Sharing data between communities can be difficult due to ownership and privacy concerns. • Limitations of the data may not be known or communicated. • Datasets are increasingly large and complex.	• Develop a consensus-based data architecture, data fields, and nomenclature across communities. • Create best practices for desensitizing data to enable better data sharing. • Increase transparency of data limitations. • Advance AI & ML approaches for data aggregation and data interrogation.

5.3. Data Dissemination, Sharing, & Decision Making

5.3.1. Current Status

The final piece of the analytical and data workflow is the dissemination of aggregated data for the purposes of educating, sharing, and/or decision making. While this sometimes happens within a community (*i.e.*, using aggregated law enforcement data to take down a drug distribution network), conversations at the workshop largely focused on conveying data to the public. How data was disseminated from communities to the public, however, varied widely. The simplest format for dissemination is one-on-one discussions between a practitioner and a customer. This interaction most frequently occurs in harm reduction settings where harm reductionists educate PWUD on the dangers of what is in the drug supply. Similarly, harm reduction organizations discussed using whiteboards in their facilities to track trends and provide PWUD relevant information in an easily digestible format.

Larger scale dissemination efforts were found to take three formats – 1) alerts, 2) reports, bulletins, or fact sheets, and 3) web-based interactive dashboards. Alerts – which could be sent out by text, email, or social media are meant to inform people when a new, particularly dangerous threat has been found in the drug supply in their geographical area. These alerts are typically written in plain language, are easy to read, and are brief. Alerts may be issued to the public or be targeted at communities involved in drug detection (public health, law enforcement, emergency medicine, etc.). Public health and law enforcement most commonly use alerts, though who issues the alert varies. In some jurisdictions, it is the individual agency, while in others, alerts are issued from a centralized entity within the state or local government.

Reports, bulletins, and fact sheets are used to convey historical trends, emerging findings, or other key pieces of information to the public. These are often released at regular intervals with structured formatting and graphics conveying things like most frequently detected drugs, drug trends over time, or unique packaging of drug products. Documents may be specific to geographical regions or discuss data at a regional or national level. Every community released a report, bulletin, or fact sheet of some kind.

The final method of dissemination is the development and deployment of interactive, web-based dashboards that allow communities to convey their information to the largest possible audience. Like reports, dashboards often convey historical data. However, instead of a static snapshot, dashboards enable people to manipulate the data to observe different trends or different periods in time. Dashboards are published by a range of agencies and organizations from non-profit to state and local to federal. In addition to public-facing dashboards, there are also internal dashboards available only to those in specific communities. These dashboards may contain law enforcement sensitive and/or personal identifiable information and are used to advance investigations, target overdose prevention efforts, or identify shipments coming into the country that may contain compounds of interest. Other ways information is disseminated within, and occasionally across, communities include collaborative calls, scientific publications, conference proceedings, and workshops.

Once disseminated, data can be used to drive education, community engagement, and decision-making efforts. Educating and informing PWUD at harm reduction sites on the risks of the drug supply along with safe use procedures is one way this data can be used. Conveying this information to the public so they are aware of the drugs that are present as well as the resources that are available for those facing addiction is another goal of these data dissemination efforts. Looking at aggregated data over time can be used to evaluate the efficacy of intervention or interdiction efforts (in law enforcement and public health) or the impact of workflow modifications in forensic laboratories. This type of data can also be used to inform, and support, implementation of services in an equitable manner. Lawmakers routinely use aggregated data to drive policy and budget decisions. One example of this can be seen by policymakers in Maryland and California who used drug data collated by the EDDS group[149] to implement legislation requiring hospitals to test for fentanyl[152].

As part of the workshop, participants were asked what data they wish they had. A summary of their responses is provided in the callout box below. As expected, many wanted more timely and comprehensive data and expressed difficulties in getting that data from other

communities. Interestingly, there were instances where, because of a misunderstanding of scope or capabilities, data one community thought existed, was available and complete had serious limitations or was not available at all.

Callout Box 8. Data I Wish I Had.

Question

Workshop participants were asked, "What types of data or datasets do you wish you had access to?".

Responses

Bolded items were mentioned by all stakeholder communities.

- **Timely fatal & non-fatal overdose toxicology data (U.S. and international).**
- **Drug trends at the regional, national, and international levels.**
- **Information on typical sample purity / quantitative results from drug samples.**
- **Information on common drug - cutting agent combinations.**
- **Timely drug seizure data and drug checking data (regional and national).**
- Real-time information on drugs entering the country through the borders.
- Timely reference information on emerging compounds to include spectral data, chemical properties, and toxicity.
- Information on how drugs moved throughout the country and within a region.
- The ability to link and overlay drug seizure data with overdose data in real-time.
- The ability to link analytical results with markings on pills or drug packaging.
- Increased availability of hospital toxicology testing data.
- Information to understand what a PWUD thought they purchased and what was received.

5.3.2. Challenges

Challenges and barriers to sharing data in this context largely mirror the challenges and barriers discussed in 5.2.2. Sensitivity of the data, whether perceived or real, can represent a major barrier for sharing data across communities and with the public. These efforts can be complicated by lack of standardization, and lack of conveyance and transparency around what conclusions can, and more importantly cannot, be drawn.

Dissemination of data to the public has its own set of challenges and barriers. Ensuring the data, whether that be an alert, a bulletin, or a dashboard, is accessible to customer base or the public is critical. This could mean needing to make sure information is available in multiple languages and is understandable by the public. Understanding that the most vulnerable population may not have access to the internet means that disseminating information in multiple formats is a necessity. Care must also be taken to ensure that information is conveyed in a non-stigmatized way. Finally, strategies to minimize alert fatigue are missing. Many participants voiced concerns that notifying the public of potentially dangerous substances in the drug supply too frequently may result in people ignoring the notifications, thereby missing the most critical notifications when they are released.

As with data aggregation, it can be challenging to convey the limitations, and significance, of the data in a way that is understood by the person digesting the data. For instance, policymakers may look at data from the analysis of used drug paraphernalia to understand if the cocaine supply is contaminated with fentanyl. Since a single syringe is often used with multiple different substances, a high prevalence of co-detection of cocaine and fentanyl may be incorrectly interpreted as a contaminated supply. Likewise, a report that is released and says a new synthetic opioid was detected in 10 samples, with no additional context, can be interpreted in many ways. Without additional information, such as the total number of samples tested was 1,000 and therefore the synthetic opioid was only present in 1% of samples tested, incorrect conclusions may be drawn. The lack of context behind data is further complicated by

the volume of data that is being reported on a regular basis. This type of data overload presents challenges when conflicting reports or bulletins are released.

A final challenge, which was an acute concern for the public health community, is that disseminating data to the public can result in it being used in a harmful manner. An example of this is law enforcement using data from a drug checking site to specifically target PWUD.

5.3.3. Opportunities

Opportunities for increased sharing of aggregated data are similar to those discussed in the Section 5.2.3. The development of best practices, standards, architectures, and common nomenclature for data reporting and sharing will enhance the ability to share aggregated data in addition to individual data. Best practices for removing sensitive components of data also applies here and could increase the ability of communities to readily share information.

Opportunities also exist to increase the effectiveness of data dissemination. Recognizing that language and technology barriers can restrict access to information, communities can make concerted efforts to ensure data is available in multiple languages and in multiple formats (print, electronic, etc.) when possible. It is also important to make sure that that the language used is non-stigmatizing to not alienate vulnerable populations. Making sure the data is displayed in an engaging manner will also increase its utility.

It is also important to develop guidelines or best practices for how to convey the limitations of the data to those who will use it. This must be done in a clear and concise manner and be sure to address limitations surrounding analytical methods, sample size, blind spots, sample type, and other caveats. Preventing the misinterpretation of data is the onus of the one generating the data, and oftentimes they may not be able to predict how others will try to use the data. Having a best practice for conveying limitations that is developed with input from all communities could help alleviate this concern.

The final set of opportunities to address data sharing, dissemination, and decision-making challenges is to increase the cross-governmental and cross-agency communication at all levels. Increased dialogue, through one-on-one conversations, webinars, workshops, or other means to discuss trends, challenges, and opportunities for collaboration is vital to addressing this epidemic. These types of interaction are critical to breaking down silos and sparking innovative and invigorating ideas and assessing the efficacy of drug checking programs and other prevention efforts. Opportunities to leverage expertise across communities should also be explored.

The ability to improve data sharing and dissemination across communities and across agencies could have a profound impact on addressing key overarching challenges of the drug overdose epidemic. Increasing discussions between forensic scientists, medical doctors, clinical testing laboratories, and policymakers could drive meaningful changes to toxicology testing panels. Increased communication and data sharing between customs, law enforcement, and public health entities could better link overdoses to drug trafficking networks – enabling law enforcement to dismantle those supplying dangerous substances. Likewise, having law enforcement alert public health entities of an eminent drug bust would allow public health

agencies to increase resources in the area and support those PWUD who will be faced with changes to their supply.

Collating timely data from multiple entities could enable the implementation of predictive analytics or trend forecasting, enabling communities to understand when a change in the drug supply may occur before it happens. This type of analysis could also be used to identify when an outlier area may be experiencing a unique outbreak. Increased sharing of data across states and at a national level could help drive policy decisions by providing actionable data to understand the impact of drug checking or other prevention modalities.

Callout Box 9. Major Challenges and Opportunities in Data Dissemination.

Challenges	Opportunities
• Conveying the statistical relevance, blind spots, and limitation of data in a digestible way. • Understanding that the way data is disseminated may not be accessible by some (*i.e.*, language and technology barriers) • Frequent alerts can minimize their effectiveness. • Ensuring data is not misused in a harmful manner.	• Harmonize naming and formatting across dissemination methods and across communities. • Create best practices to ensure disseminated data is accessible to the public and is engaging. • Develop guidelines for conveying the limitations, blind spots, and significance of data. • Document and replicate data sharing successes.

6. Potential NIST Action Items

Given NIST's focus on measurement science and standards development, there are unique opportunities for the agency to assist other communities in illicit drug detection, analysis, and monitoring. Based on the challenges and barriers identified at the workshop, there are five areas where, given an expansion of efforts and resources, the NIST mission is well aligned to support: advancing analytical measurements, creating data analysis tools, developing standards, providing education and training, and convening communities.

- **Advancing Analytical Measurements –** Measurement science is a core competency that NIST can leverage to assist communities address illicit drug detection and identification challenges. While NIST already has ongoing research efforts, these could be expanded to incorporate additional areas. Expansion of these efforts could include:
    - Development of new analytical technologies for the detection of drugs and other compounds of interest.
    - Development of analytical methods that provide more comprehensive, sensitive, or objective results both in the field and in the laboratory.
    - Development of analytical methods for the quantitation of compounds of concern in drug samples.
    - Development of analytical methods to improve the identification of novel compounds.
    - Supporting other government and academic entities in addressing measurement challenges related to forensic and clinical toxicology.
    - Supporting or collaborating with other government and academic entities in addressing measurement challenges related the analysis of drugs in wastewater.
- **Creating Data Analysis Tools –** The need for data analysis tools transcends all the communities represented at the workshop. These tools could assist personnel making decisions in the field or assist agencies with data aggregation and dissemination. While the development of data analysis tools is an ongoing and growing effort at NIST there are opportunities to expand these efforts to provide additional resources. Expansion of these efforts could include:
    - Development of new algorithms for spectral library searching.
    - Creation of a framework for using statistics in reporting results for forensic drug analysis.
    - Development of predictive and prescriptive data analytic approaches for communities.
    - Development of data fusion approaches to merge, and compare, chemical and non-chemical data.
    - Creation of approaches to detect potential novel compounds in complex spectral data.

- **Developing Standards (Physical, Reference, and Documentary) –** The need for physical, reference, and documentary standards was continually expressed throughout the workshop. Given the longstanding standards development efforts at NIST, related efforts to assist communities could include the following:
    - Producing physical reference standards of new and emerging compounds.
    - Producing reference data for additional analytical techniques aside from MS.
    - Guidelines for naming and categorizing drugs and metabolites.
    - Guidelines for safe handling of suspected opioid-containing samples.
    - Standards for data collection and nomenclature.
    - Standards for analytical methods and reporting.
    - Guidelines to convey data limitations.
    - Creation of a quality assurance program to ensure consistency of testing in fields where there is not an accreditation process.
- **Providing Education & Training –** The need for additional training and education resources ranged from instrumentation use to data interpretation for conveying results to the public. NIST could support education and training as it relates to measurement science and standards in the following ways:
    - Workshops and webinars on data analysis and interpretation.
    - Workshops and hands-on training for personnel to learn how to use analytical instruments.
    - Workshops and guidance demonstrating why safe handling procedures are needed.
    - Internship, sabbatical, and guest researcher opportunities to support research and standards development initiatives.
- **Convening Communities –** The value of bringing together people from across communities involved with drug detection, interdiction, monitoring, and overdose prevention or treatment, was made evident during this workshop. NIST could continue to support cross-community convening efforts by organizing additional engagements focused on:
    - Data standardization and nomenclature harmonization.
    - Analytical method development and standardization.
    - Safe handling protocols to prevent exposure.
    - Cross-community needs assessment.

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Appendix A. Workshop Agenda

Tuesday February 13th, 2024	
9:00	Opening Remarks *Chuck Romine – NIST*
9:15	Opening Plenary: Drug Detection, Identification, and Monitoring – Where Are We? *Cece Spitznas– Office of National Drug Control Policy* *Dave Fluty – Customs and Border Protection* *Natanya Robinowitz – Centers for Disease Control and Prevention*
10:30	Break
10:50	Practices, Instrumentation, and Challenges: Field Analysis *Jason Bienert – Johns Hopkins University* *Daniel DiAntonio – Homeland Security Investigations* *Dennise Montero – Customs and Border Protection*
12:20	Lunch
1:30	Practices, Instrumentation, and Challenges: Laboratory Analysis *Sara Kern – Food and Drug Administration* *Amber McConnell – Maryland State Police, Forensic Sciences Division* *Alex Krotulski – Center for Forensic Science Research & Education*
3:00	Break
3:20	Practices, Instrumentation, and Challenges: Medical & Post-Mortem *Sara Schreiber – Wisconsin Lutheran College* *Malik Burnett – Center for Harm Reduction Services, Maryland Dept. of Health*
4:20	Discussion & Debrief *Marcela Najarro & Edward Sisco – NIST*
5:00	Conclude Day 1
Wednesday February 14th, 2024	
9:00	Day 1 Recap *Marcela Najarro & Edward Sisco – NIST*
9:15	Data Uses and Challenges: Public Health & Medical *Emily Payne – New York Department of Health* *Traci Green – Brandeis University* *Erin Artigiani & Amy Billing – University of Maryland (CESAR)*
10:30	Break
10:50	Data Uses and Challenges: Customs, Law Enforcement, & Forensics *Ronald Borrego – Customs and Border Protection* *John Cook – Washington/Baltimore HIDTA* *Eric Wisniewski – Drug Enforcement Administration* *Sally Aiken – Spokane County Medical Examiner (Retired)*
12:30	Discussion, Debrief, & Next Steps *Marcela Najarro & Edward Sisco – NIST*
1:00	Conclude Day 2

Appendix B. Speakers and Participants

Sally Aiken
Spokane Co. Medical Examiner

Leonardo Angelone
NIDA

Meghan Appley
NIST

Erin Artigiani
University of Maryland, CESAR

Caitlin Berry
NIST

Jason Bienert
Johns Hopkin Bloomberg School of Public Health

Amy Billing
University of Maryland, CESAR

Ronald Borrego
CBP

Jason Bory
CBP

Thinh Bui
NIST

Malik Burnett
Maryland Dept. of Health, Center for Harm Reduction Services

Briana Capistran
NIST

Ronald Clouse
DEA / Booz Allen Hamilton

John Cook
Washington / Baltimore HIDTA

Daniel DiAntonio
HSI

David Fluty
CBP

Sabrina Gattine
Maryland Office of Overdose Response

Traci Green
Brandeis University

Stephen Hardesty
Howard County Dept. of Fire & Rescue Services

Anthony Kearsley
NIST

Sara Kern
FDA

Yordon Kostov
NIDA

Amudhan Krishnaswam Usha
NIST

Alex Krotulski
Center for Forensic Science Research & Education

Dennis Leber
NIST

Emily Lockhart
DEA

Amber McConnell
Maryland State Police, Forensic Sciences Division

Dennise Montero
CBP

Marcela Najarro
NIST

David Newton
NIST

Emily Payne
New York State Dept. of Health

Natanya Robinowitz
CDC

Elizabeth Robinson
NIST

Margaret Rybak
Maryland Dept. of Health, Center for Harm Reduction Services

Sara Schreiber
Wisconsin Lutheran College

Edward Sisco
NIST

Cecelia Spitznas
ONDCP

Matthew Staymates
NIST

Jason Williams
University of Washington, ADAI

Eric Wisniewski
DEA

Andrea Yarberry
NIST

Appendix C. Slide Prompts for Speakers

C.1. Day 1: Analytical

Overview

- **Bio:** Brief bio of who you are.
- **Mission / Goal:** What is your mission or goal in your career / organization?
- **Stakeholder:** Who uses the data you collect?
- **Two Challenges:** What are two of the greatest challenges you feel you face in your job, preferably related to drug analysis / detection?

A Day in the Life

- *On this slide, we ask you walk us through what a "normal" day at work looks like. Please address the following, but feel free to add to these points, as necessary. Also, feel free to add additional slides if you'd like.*
    - **Operational Environment:** Where do you work – are you mobile or at a fixed site, do you have dedicated lab space, etc.?
    - **Technology Used:** What type of technology do you use for illicit drug detection / analysis?
    - **Types of Samples Commonly Observed:** Do you typically see powders, pills, plant material? Are these materials pure, cut, etc.? (Feel free to add in historical perspective here)
    - **Safety / PPE:** What type of personal protective equipment do you use when handling samples (*e.g.*, gloves, masks, eyewear, etc.)?
    - **What Type of Data you Need:** Do you need presumptive or confirmatory information? Do you just need to know if something contains an illicit substance, a class of drug (*e.g.*, opioid), or the specific drug(s)?
    - **Data Interpretation:** How do you interpret data? Are you looking for red-light / green-light, do you interpret spectra, etc.?
    - **Who Gets Your Data:** Do you share your data with any other entities or parts of your organization (*e.g.*, HIDTA, CDC, NFLIS)? How often do you share data?

Purchasing, Training, & Implementation

- **Technology:** Discuss how your organization handles identifying, and purchasing, new technology. Do end-users have a say? Are there benchmarks new technology must meet? Do you purchase based on other agency recommendations? How frequently do you purchase new technology? Also, include any issues that come up identifying new technology (*i.e.*, you wish you could demo technology beforehand).
- **Training:** Do you typically receive any additional training beyond the initial vendor training? Do you have a "train the trainer" system? Do you have in-person training or virtual training? Are there different levels of operators? Do you wish you received more training, or a different type of training?
- **Implementation:** What resources (if any) do you leverage for implementing new technology? Do you need help with implementing new technology?

Important Operational / Environmental Considerations

- *On this slide, we ask you to discuss what are the important operational and environmental considerations that one needs to consider when implementing new technology into your field. This can include the ambient environment (are you outside, are you working in extreme temperatures), the transportation aspect (do instruments need to be able to be easily moved around a location), the time without access to electricity (do you need full day battery), the form the sample needs to be in (can you unpackage a sample or not), and any other considerations you feel are important.*
    - *If there are multiple "environments" (i.e., some testing is done in field and other in lab) please include considerations for each environment (ideally on separate slides).*

My Ideal Technology(ies)

- *On this slide, we ask you to discuss what the "ideal" instrument would look like for you. Discuss things like form factor (footprint), what type of results would it provide you, how would you introduce a sample, how fast is an analysis, etc.*
    - *If there are multiple "environments" (i.e., some testing is done in field and other in lab) please discuss your ideal instrument(s) for each environment individually (ideally on separate slides).*

Data I Wish I Had

- *On this slide, we ask you to discuss what data you wish you had access to but don't (or data you have access too but wish you had it more frequently or sooner). Also discuss how this data would be important to assisting you in achieving your mission.*
    - *For example, do you wish you had access to drug trend information across the country, more timely or complete fatal overdose data, drug data from a different community (e.g., law enforcement), etc.*

Additional Thoughts or Considerations

- *Include here any additional thoughts or considerations related to drug detection / analysis. This could include whether you feel your experience is generalizable to the rest of the country, what you feel future needs may be, other things you wish you had to help do your job, etc.*

C.2. Day 2: Data

Overview

- **Bio:** Brief bio of who you are.
- **Mission / Goal:** What is your mission or goal in your career / organization?
- **Stakeholder:** Who uses the data you collect?
- **Two Challenges:** What are two of the greatest challenges you feel you face in your job, preferably related to drug analysis / detection?

A Day in the Life

- *On this slide, we ask you walk us through what a "normal" day at work looks like. Please address the following, but feel free to add to these points, as necessary. Also, feel free to add additional slides if you'd like.*
    - **Data Collector or End-User:** Are you someone who collects and collates data, or do you take existing data and act on it?
    - **Data Sources:** Where do you get your data from (surveys, health records, forensic laboratories, etc.)?
    - **What Type of Data you Need:** Do you need presumptive or confirmatory information? Do you just need to know if something contains an illicit substance, a class of drug (*e.g.*, opioid), or the specific drug(s)?
    - **Data Interpretation:** How do you interpret the data you receive? Do you rely on algorithms, manual interpretation, something else?
    - **Who Gets Your Data:** Do you share your data with any other entities or parts of your organization (*e.g.*, HIDTA, CDC, NFLIS)? How often do you share data?
    - **Dashboards:** Do you support or regularly access a public-facing dashboard (*e.g.*, for trend analysis, hot spot detection)?

Utilization of Data

- *On this slide, we ask you discuss how your agency utilizes data (for example, support implementation of services, surveillance, inform policy, etc.). Please include what current "state of the art" is as well as what you wish you could do if there were no barriers.*
    - *Also, on this slide (or a second slide if needed), we ask you speak to your current data analytics / data processing capabilities. Include things like how you tackle data collection, scrubbing, analysis, and modeling (if appropriate).*

Important Data Considerations & Gaps

- *On this slide, we ask you discuss the important considerations or caveats related to the data you work with. These can include limitations or gaps related to data quality, timeliness of the data, completeness of the data, etc.*

Data Interoperability

- *On this slide, we ask you to discuss anything related to data interoperability that you feel is important. Include things like what data linkages are currently being made, what data linkages you think are important to be made in the future, how increased interoperability could make you more effective at your mission, etc.*

Data I Wish I Had

- *On this slide, we ask you to discuss what data you wish you had access to but don't (or data you have access too but wish you had it more frequently or sooner). Also discuss how this data would be important to assisting you in achieving your mission.*
    - *For example, do you wish you had access to drug trend information across the country, more timely or complete fatal overdose data, drug data from a different community (i.e., law enforcement), etc.*

Additional Thoughts or Considerations

- *Include here any additional thoughts or considerations related to drug detection / analysis. This could include whether you feel your experience is generalizable to the rest of the country, what you feel future needs may be, other things you wish you had to help do your job, etc.*

Appendix D. List of Symbols, Abbreviations, and Acronyms

AI-MS
ambient ionization mass spectrometry

CBP
Custom and Border Protection

CDC
Centers for Disease Control and Prevention

DEA
Drug Enforcement Administration

FDA
Food and Drug Administration

FTIR
Fourier transform infrared spectroscopy

GC-IR
gas chromatography infrared spectroscopy

GC-MS
gas chromatography mass spectrometry

GC-VUV
gas chromatography vacuum ultraviolet spectroscopy

HIDTA
High Intensity Drug Trafficking Areas

HSI
Homeland Security Investigations

LC-HRMS
liquid chromatography high-resolution mass spectrometry

LC-IMS-MS
liquid chromatography ion mobility mass spectrometry

LC-MS/MS
liquid chromatography tandem mass spectrometry

LIMS
laboratory information management system

MS
mass spectrometry

NFLIS
National Forensic Laboratory Information System

NHTSA
National Highway Traffic Safety Administration

NII

non-intrusive inspection

NIOSH
National Institute of Occupational Safety and Health

NIST
National Institute of Standards and Technology

NMR
nuclear magnetic resonance spectroscopy

ONDCP
Office of National Drug Control Policy

OSAC
Organization of Scientific Area Committees

PPE
personal protective equipment

PWUD
person who uses drugs

SAMHSA
Substance Abuse and Mental Health Services Association

SERS
surface enhanced Raman spectroscopy

SUDORS
State Unintentional Overdose Reporting System

SWGDRUG
Scientific Working Group for the Analysis of Seized Drugs

USPIS
United States Postal Inspection Service

icon used to represent the customs and border interdiction community

icon used to represent the public health and harm reduction communities

icon used to represent the law enforcement and first responder communities

icon used to represent the forensic science community

icon used to represent the emergency medicine community

icon used to represent the medical examiner, coroner community

icon used to represent the policymaker community

icon used to represent pure drug or precursor

icon used to represent street level, or cut, drug sample

icon used to represent drug paraphernalia

icon used to represent biological specimens collected for drug analysis