Received: 28 February 2023 | Revised: 6 July 2023 | Accepted: 6 July 2023

DOI: 10.1111/1556-4029.15341

JOURNAL OF FORENSIC SCIENCES AAFS

ORIGINAL PAPER

Digital & Multimedia Sciences

Decoding hidden darknet networks: What we learned about the illicit fentanyl trade on AlphaBay

Marie-Helen Maras PhD[1] | Kenji Logie MS[2] | Jana Arsovska PhD[3] | Adam Scott Wandt JD[4] | Bryce Barthuly MS[2]

[1]Department of Security, Fire, and Emergency Management and Center for Cybercrime Studies, John Jay College of Criminal Justice, City University of New York, New York, New York, USA

[2]John Jay College of Criminal Justice, City University of New York, New York, New York, USA

[3]Department of Sociology, John Jay College of Criminal Justice, City University of New York, New York, New York, USA

[4]Department of Public Management, John Jay College of Criminal Justice, City University of New York, New York, New York, USA

Correspondence
Marie-Helen Maras, Department of Security, Fire, and Emergency Management and Center for Cybercrime Studies, John Jay College of Criminal Justice, City University of New York, 524 West 59th Street, Haaren Hall, Room 43311, New York, NY 10019, USA.
Email: mmaras@jjay.cuny.edu

Funding information
National Institute of Justice, Grant/Award Number: 2019-R2-CX-0018

Abstract

The opioid epidemic, impacted from the proliferation of fentanyl, has added impetus to the need to detect fentanyl, sources of fentanyl, and places where fentanyl and drugs adulterated with fentanyl are available. Many darknet marketplaces (DNMs) have rules that ban fentanyl. However, it is unclear how these affect the fentanyl market. Using the AlphaBay DNM as a case study, we conducted mixed methods qualitative research. We scraped and analyzed data from the AlphaBay I2P website using, among other methods, content and social network analysis, to uncover hidden fentanyl networks. Our research highlights the next evolution of darknet marketplaces – the migration of DNMs from Tor to I2P and the methods that can be used identify fentanyl networks, irrespective of where sites are: I2P, Tor, or multihomed on I2P and Tor. Despite its ban in the Global AlphaBay Rules, our research revealed the sale of fentanyl on the AlphaBay DNM. Unlike previous studies, our findings predominantly revealed the covert sale of fentanyl on AlphaBay and predatory vendors selling illicit drugs, which unbeknownst to buyers, contained fentanyl. To a lesser extent, our findings identified the overt sale of fentanyl patches on AlphaBay. Although we examined only one DNM, the prevalence of the covert sale of fentanyl and the presence of predatory vendors underscores the importance of research that decodes the language of vendors who surreptitiously sell fentanyl or drugs adulterated with fentanyl or other illicit substances. The results of our research can inform strategies aimed at disrupting and dismantling DNM fentanyl networks.

KEYWORDS
AlphaBay, content analysis, darknet, drug trade, fentanyl, I2P, predatory vendors, social network analysis

Highlights

- Fentanyl is sold on darknet marketplaces (DNMs) despite bans.
- Predatory vendors surreptitiously sell drugs laced with fentanyl on DNMs.
- Content analysis can be used to uncover covert language used by fentanyl networks.
- Social network analysis can be used to map fentanyl networks.
- Darknet research can inform strategies aimed at detecting and disrupting the illicit fentanyl trade.

1 | INTRODUCTION

Opioid-related deaths, impacted in large part from the proliferation of illegal fentanyl [1,2], added impetus to the need to detect sources of fentanyl and places where fentanyl is advertised, sold, purchased, and/or otherwise traded, including spaces where illicit drugs are, unbeknownst to users, adulterated with fentanyl. The opioid epidemic and related overdose deaths eventually led to an increase in law enforcement attention to places where illegal fentanyl, its analogues, and derivatives (hereafter fentanyl) are sold [3]. One of these places is the darknet, which includes sites that are not accessible using traditional clearnet search engines, such as Google and Bing, and can only be accessed using specialized routing software (e.g., Tor and I2P). Overdose deaths and the law enforcement authorities increased attention on fentanyl contributed to the banning of the trade of this illicit substance on several darknet marketplaces (DNMs). This fentanyl ban is included in the terms of use, rules, and/or community guidelines of these DNMs as a prohibited item. For example, the second iteration of the AlphaBay DNM banned fentanyl and fentanyl-laced/based substances in its *Global AlphaBay Rules* ("N[o] fentanyl or fentanyl-laced/based substances even if it is done ('correctly'). We no longer allow fentanyl or substances laced/based on it due to buyer safety…"; November 2022). While the exploration of the reasons for the fentanyl bans on DNMs (e.g., increased law enforcement attention, concerns about overdose deaths and substances adulterated with fentanyl, etc.) is beyond the scope of this article, our work identifies the illicit fentanyl trade on a DNM, AlphaBay, regardless of this ban.

Our study examines a DNM to detect the overt and hidden sale of fentanyl and uncover hidden fentanyl networks. The objectives of this article are threefold. Using AlphaBay as a case study, first, this article identifies the ways fentanyl is illegally traded on the site either overtly or covertly by carefully examining code words that vendors and buyers use to signal that they are trading fentanyl. Second, since fentanyl is often traded covertly, it discusses the research methods applied in this darknet study and illustrates new ways to conduct fentanyl-related research and detect fentanyl on DNMs. Third, by applying social network analysis, the goal is to identify the overt and covert sale of fentanyl connections between buyers and fentanyl vendors on AlphaBay. The overarching research question in this study is: How can fentanyl be detected on DNMs? The results of our study can be used to fill the gaps in knowledge and practice by informing law enforcement, digital forensic investigators, policymakers, and practitioners about the novel methods required for monitoring the trade in illicit fentanyl on the darknet, detecting fentanyl vendors on DNMs, "decoding" the language used on these sites, and understanding and predicting emerging threats relating to fentanyl.

2 | LITERATURE REVIEW

The illicit fentanyl trade on DNMs is a topic of enormous importance for academics, public health officials, and criminal justice practitioners due to the rapid increase in fentanyl-related overdose deaths in the past few years. Nevertheless, the illicit trade of fentanyl, especially the one occurring on DNMs, has remained an understudied topic. The lack of understanding of how fentanyl networks communicate on DNMs serves as an obstacle in the identification of these networks and the ultimate reduction of the illicit sale of fentanyl. The below sections elaborate on the social relevance of this topic and provide a brief overview of the limited research on fentanyl and DNMs.

2.1 | The opioid epidemic, deaths, and fentanyl

In the United States, the significant rise of opioid-related deaths led to its declaration as an epidemic and a national public health emergency in 2017 [4,5]. Fueling the U.S. opioid epidemic and public health emergency are novel synthetic opioids (NSOs), a varied class of illicit opioids, including controlled substances (according to the U.S. Controlled Substances Act of 1970 and subsequent amendments) such as fentanyl, its analogs, and other non-fentanyl synthetic opioids [1,2,6]. According to the U.S. Centers for Disease Control and Prevention (CDC), fentanyl is considered "up to 50 times stronger than heroin and 100 times stronger than morphine" and "over 150 people die every day from overdoses related to synthetic opioids like fentanyl" [1]. In 2021, over 66% of the more than 106,000 reported drug-related deaths in the U.S. were attributed to synthetic opioids; with fentanyl being predominantly responsible for synthetic opioid-related deaths [2,6]. While fentanyl has legitimate medical uses, its illegal manufacture, distribution, sale, and unregulated consumption has contributed to the rise in overdose deaths in the U.S. [7]. In mid-2023, the U.S. Drug Enforcement Administration (DEA) posted on the homepage of its website that it had already seized more than 40.5 million pills and 5600 pounds of fentanyl powder [8]. The U.S., however, is not the only country experiencing a fentanyl-related crisis, Canada, Australia, Estonia, Germany, Finland, and the United Kingdom, among other countries, have experienced increases in fentanyl-related overdoses and deaths [9].

The illegal fentanyl trade is not only deadly but also very profitable for criminals because it is inexpensive and easier to manufacture than other drugs, such as heroin. The same dose of fentanyl was reported to be a fraction of the cost of the same dose of other opioids, enabling distributors to "cut costs by over 80% by substituting fentanyl for more expensive opioids" [10].

Further fueling the opioid epidemic in the U.S. and opioid crisis in other parts of the world, are illegal drugs adulterated with fentanyl. These fentanyl-laced drugs are also contributing to overdose deaths [11]. Fentanyl is commonly mixed with heroin and other opioids [1]. Numerous individuals have been arrested in the United States for selling counterfeit versions of oxycodone laced with fentanyl, which resulted in overdose deaths of consumers [12–15]. In 2020, the leader of a U.S. based drug trafficking organization, Aaron Shamo, who was linked to the overdose deaths of more than 90 buyers who consumed his counterfeit oxycodone pills laced with fentanyl, was

sentenced to life imprisonment [16]. Other illegal drug manufacturers and dealers are cutting their supplies (i.e., mixing their drugs) with fentanyl because it takes very little to produce a high with fentanyl, making it a cheaper option for them [17]. Heroin, cocaine, methamphetamine, and ketamine users are often unaware that the drugs they are consuming contain this dangerous additive [18–21]. Over the last few years, there have been numerous individuals who died from overdoses from non-opioid drugs they purchased that were laced with fentanyl [22,23]. Recent increases in cocaine overdoses have been largely attributed to cocaine being frequently laced with fentanyl [24–26]. In 2020, "[o]f [the] 980 cocaine deaths [in New York City], 81% involved fentanyl" [27]. In January 2023, a federal court in Manhattan, New York, convicted a cocaine dealer, Billy Ortega, for distributing cocaine laced with fentanyl that killed three people in New York City on the same day [28]. The rate of increase of the number of opioid-related deaths involving fentanyl shows a worrisome trend and illustrates the need for proactive measures to detect these drugs on the market and expedite law enforcement intervention.

2.2 | Sources of fentanyl

China and to a greater extent Mexico are currently considered the main source countries of the supply of illegal fentanyl and related substances to the United States. [6] Until around 2019, however, traffickers in China were considered the primary direct source of fentanyl to the United States [29]. A DEA intelligence report revealed that:

> Effective May 1, 2019, China officially controlled all forms of fentanyl as a class of drugs [...] The implementation of the new measure includes investigations of known fentanyl manufacturing areas, stricter control of internet sites advertising fentanyl, stricter enforcement of shipping regulations, and the creation of special teams to investigate leads on fentanyl trafficking. These new restrictions have the potential to severely limit fentanyl production and trafficking from China (p. 3) [30].

While China is still considered a primary source of the chemicals used to produce fentanyl [31], actions taken by the Chinese government to control fentanyl-related substances as well as the stricter monitoring of mail in China, led to a shift in the primary direct source country for the supply of fentanyl to the United States.

According to the DEA's 2020 National Drug Threat Assessment, Mexico is now a more direct supplier of fentanyl to the United States than China [6,32]. This DEA threat assessment report also identified the Sinaloa cartel and the Cártel de Jalisco Nueva Generación (CJNG) as groups trafficking fentanyl from Mexico to the United States [30]. The Wilson Institute and InSight Crime likewise identified the role of these two cartels in fentanyl trafficking [33]. Mexican organized criminal groups primarily obtain the chemicals they use for fentanyl production from sources in China [6]. Mexican and U.S. law enforcement have seized large quantities of fentanyl, fentanyl-laced opioids, and chemical precursors from organized criminal groups operating in Mexico [6,30,34]. For example, in 2022, Mexican military officials seized, among other things, 542 kg of fentanyl and more than 71,000 kg of chemical precursors from a warehouse in Culiacán, Sinaloa [35]. A year later, in February 2023, in the same area (Culiacán, Sinaloa), Mexican authorities claimed that they discovered "the biggest fentanyl pills manufacturing lab in history" and seized pressed pills, pill machines, and chemical precursors that could be used to make fentanyl and other drugs [35]. Moreover, Mexican organized criminal groups have illicitly traded counterfeit opioids made to resemble 30 mg oxycodone pills ("these tablets—blue, round, stamped with 'M' on one side and '30' on the other, ...[are] increasingly referred to on the streets as 'Mexican Oxy' or 'M30s'") (p. 16) [6].

In India, traffickers have illegally manufactured fentanyl and fentanyl precursors. According to a report from the Wilson Institute and InSight Crime, "India—with its large chemical infrastructure—appears poised to make an entry into the [fentanyl] market" [33]. Chinese traffickers have also moved certain operations to other countries, such as India [36]. Chinese and Indian traffickers of fentanyl precursors operating from India have been linked to Mexican organized criminal groups and/or affiliates [37]. Therefore, although Mexico and China still remain key fentanyl source countries, "the flow of fentanyl into the United States in 2019 is more diverse compared to the start of the fentanyl crisis in 2014, with new source countries and new transit countries emerging as significant trafficking nodes" (p. 2) [30]. The trade of illicit fentanyl on darknet marketplaces further diversifies fentanyl sources and complicates efforts to stop the supply of fentanyl to the U.S. [30].

2.3 | Fentanyl and DNMs

Since the takedown of the Silk Road, which brought worldwide attention to the darknet, research on DNMs has grown. Studies have examined single DNMs (e.g., Silk Road [38,39], Evolution [40], Dream [41], and the first iteration of AlphaBay [42]) and/or multiple DNMs [43,44]. DNM studies used quantitative and qualitative research methods examining vendor characteristics [38,39,45], market structure [46], the variety, volume, and pricing of illicit goods and services [47], and comments and ratings (or feedback) on vendors and/or products [48]. Qualitative research on DNMs has included interviews with DNM users [49–51], online surveys and questionnaires [52], ethnography [53,54], and content analysis [51,55]. Social network analysis (SNA), which is used to detect and interpret social ties among nodes (i.e., actors or entities and ties connect nodes together, varying in type, direction, and strength) [56], has also been used to examine DNMs [57]. While the nodes in SNA often represent people, existing research demonstrates that this is not always the case. Networks can represent various phenomena and nodes

can take many different forms – "a fact that is often ignored by analysts in their attempt to disrupt dark networks" [56]. In the field of criminal justice, SNA has been used to address various criminological questions and serves as a tool for law enforcement to identify high-priority targets and structural vulnerabilities that may lead to the disruption and dismantlement of criminal markets [58].

Darknet research examines various illicit goods and services, predominantly illicit drugs [40,47,58], and to a lesser extent stolen data [59], malware and hacking services [41,60], firearms [61], wildlife [62,63], intellectual property [64], and counterfeit identity documents [65,66] and money [67], among other DNM offerings. While there are several studies that focus on drugs in darknet markets, there is limited research on DNM fentanyl markets. Broadhurst, Ball, and Trivedi (2020), in their seminal study of fentanyl on DNMs in 2019, identified 303 fentanyl vendors on six DNMs (Empire, Valhalla, Wall Street, Berlusconi, Tochka, and Dream Market) [44]. Out of the DNM 127,541 listings the authors reviewed, approximately 1118 included products that contained fentanyl [44]. They also observed that one of these DNMs, Dream Market, had a fentanyl ban. Nevertheless, fentanyl was still actively sold on that site; the authors identified 48 fentanyl listings [44]. Fentanyl has been banned on several DNMs [68–71], yet this does not mean that fentanyl is not sold. Similarly, in 2018 and 2019, Lamy et al. (2020) studied fentanyl and other novel synthetic opioids on Dream Market and found 33 novel synthetic opioids for sale [68]. In addition, Lokala et al. (2019), also looked at the availability of fentanyl and its analogues on two darknet sites, Agora and Dream Market, while examining trends related to accidental overdoses in Ohio [72]. This study assessed the relationship between availability of fentanyl on these two DNMs and unintentional overdoses in Ohio. The researchers identified a total of 866 fentanyl-related and 334 fentanyl analog-related product listings on both DNMs [72]. Moreover, Negri et al. (2021) studied the sale of carfentanil, an extremely potent drug (the active ingredient in a tranquilizer used by veterinarians) on 19 DNMs [73]. This study identified 181 listings for carfentanil and discovered 63 carfentanil vendors on 19 DNMs [73]. These studies involved quantitative research. Novel qualitative analyses of DNMs can reveal essential information about the illicit fentanyl trade, particularly the covert sale of fentanyl, which cannot be identified by quantitative studies.

2.4 | The evolution of DNMs: Policy, practices, and current shift from Tor to I2P

DNM sites have been shut down by law enforcement agencies, scammers, hackers, and distributed denial of service (DDoS) attacks [74]. Scammers have caused distrust in DNMs [73,75–77], particularly because numerous DNM sites turned out to be scam markets (e.g., Sheep, Atlantis, TorMarket, Empire, Andromeda, etc.), shutting down the site before giving users advance notice and allowing them to withdraw their cryptocurrencies [74]. Between 2010 and 2021, the most common reason for DNM sites closures was exit scams [74,78]. The second most common reason for a DNM site going offline was a voluntary closure, often due to security reasons [74]. Unlike exit scams, DNM sites that voluntarily close notify users in advance and afford them the opportunity to remove their cryptocurrencies from the platform before shutting down (e.g., Agora, Cannazon, White House Market, etc.) [79].

The shutdowns of DNMs and the rise in exit scams has led to an overall distrust among DNM users. According to the Maras et al. (2023), "the trustworthiness (i.e., a trait of being honest and reliable) of vendors plays a critical role in illicit transactions and the sustainability of the illegal trade of goods and services, such as drugs, on DNMs" (p. 278) [69]. To ensure DNM continuity, site administrators determine which trust signals are built into their platforms (e.g., escrow systems, ratings and feedback mechanisms) to create feelings of user security and build trust in what is essentially a zero-trust environment [75,80]. Consequently, DNM shutdowns led to an increase in security of new and existing DNM sites and the protection of users. This increase in security was driven by both the upper-level management of darknet sites (i.e., administrators and moderators) and virtual communities of practice (i.e., users of the sites, including buyers and vendors) in an effort to improve the level of trust on DNMs [81]. Efforts to increase security also included the prohibition of items that would likely draw increased law enforcement attention to DNMs, such as child sexual abuse material and fentanyl [70]. Additionally, the security features of darknet marketplaces have evolved over time, with DNM user input [69]. The increase in Tor DNM shutdowns by law enforcement, competitors, and cyberattackers has led to the multi-homing of certain DNMs (e.g., AlphaBay, Kingdom, and Tor2Door) on I2P and multi-homing of vendors on various DNM sites. Existing DNM research has almost exclusively focused on Tor DNMs, except for a few technical studies on I2P [82,83]. We examine a multi-homed DNM site on Tor and I2P – namely, AlphaBay.

2.5 | AlphaBay: Then and now

AlphaBay was an active DNM site between December 2014 and July 2017. The site was shut down following the arrest of co-founder and administrator of AlphaBay, Alexandre Cazes (Alpha02; deceased) [84]. A joint U.S. and Dutch investigation, led by the U.S. Federal Bureau of Investigation (FBI), the U.S. DEA, and the Dutch National Police, shut down two major DNMs in 2017, Hansa and AlphaBay [85]. The agencies from the United States and the Netherlands coordinated their takedowns of the sites. The Dutch National Police took over the Hansa DNM, enabling them to control and surveil activity on the platform [86]. AlphaBay was subsequently taken offline by U.S. law enforcement action. Following AlphaBay's closure, many of the users of that site migrated to Hansa, which at the time, was under Dutch control [87]. This action provided authorities with valuable intelligence, particularly about DNM buyers and vendors. At the time of AlphaBay's shutdown in July 2017, Europol reported that AlphaBay had more than 250,000 illicit commodities listings [87].

In 2021, a new iteration of AlphaBay appeared. The founder and administrator of this version of AlphaBay was DeSnake, who was

purportedly the original co-founder of AlphaBay. DeSnake authenticated his identity by signing his messages with the PGP key used by his moniker on the original AlphaBay marketplace. As of December 2022, although this iteration of AlphaBay did not remotely have the same number of listings as the original site, it swiftly became a top DNM. As of January 2023, AlphaBay had: 17,764 active members; 1,237,158 registered buyers; 49,163 active listings; and 16 listing categories (Figure 1). This site had 16 category listings: fraud; hacking and spam; malware; drugs and chemicals; services; security and hosting; guides and tutorials; software; digital items; websites and graphic design; jewelry and precious metals; counterfeit items; carded items; automotive-related items; legitimate items; and other listings. While drugs and chemicals were the largest category on AlphaBay, fraud, guides and tutorials, digital items, hacking and spam, and counterfeit items, all had over 1000 listings.

Users attempting to access AlphaBay would first encounter an "Anti-DDoS Firewall" if accessing the marketplace using the Tor link (Figure 2A). Once the captcha was correctly entered within 60 s, the user was redirected to the login screen (Figure 2B). The user had one final hurdle after correctly entering their marketplace credentials and captcha on the login page. The user had to complete one more captcha when using either the Tor or I2P version of AlphaBay's website (Figure 2C). Once the user completed the captcha successfully, the user was given access to AlphaBay's homepage (see AlphaBay homepage in Appendix S1).

This DNM site boasted about numerous security features that were designed to allay users' concerns about their security and safety while using the site and interacting with others. In 2021, DeSnake posted announcements that acknowledged users' concerns about prior law enforcement actions and the millions lost by AlphaBay users in the seizure of the first AlphaBay site. In announcement posts, DeSnake also delineated the measures taken to secure the site, its users, and their money (e.g., DeSnake posted, "… to all the previous AlphaBay users buyers and sellers alike … I know all of you lost millions to seizure from Law Enforcement, this time around I have created a very well tested system called AlphaGuard which ensures even if seizures happen on all servers, users will be able to withdraw their funds, settle disputes and leave without a cent lost"). While AlphaBay was multihomed on Tor and I2P, DeSnake informed users that the site would transition exclusively to I2P in the near future. Nevertheless, in the beginning of 2023, Darktrain Express and Tor Times called AlphaBay a scam market and DeSnake, the administrator of AlphaBay, was accused of engaging in an exit scam. Both the AlphaBay I2P and Tor sites are no longer active and AlphaBay has been delisted as a top market on other clearnet and darknet sites that provide information about DNMs.

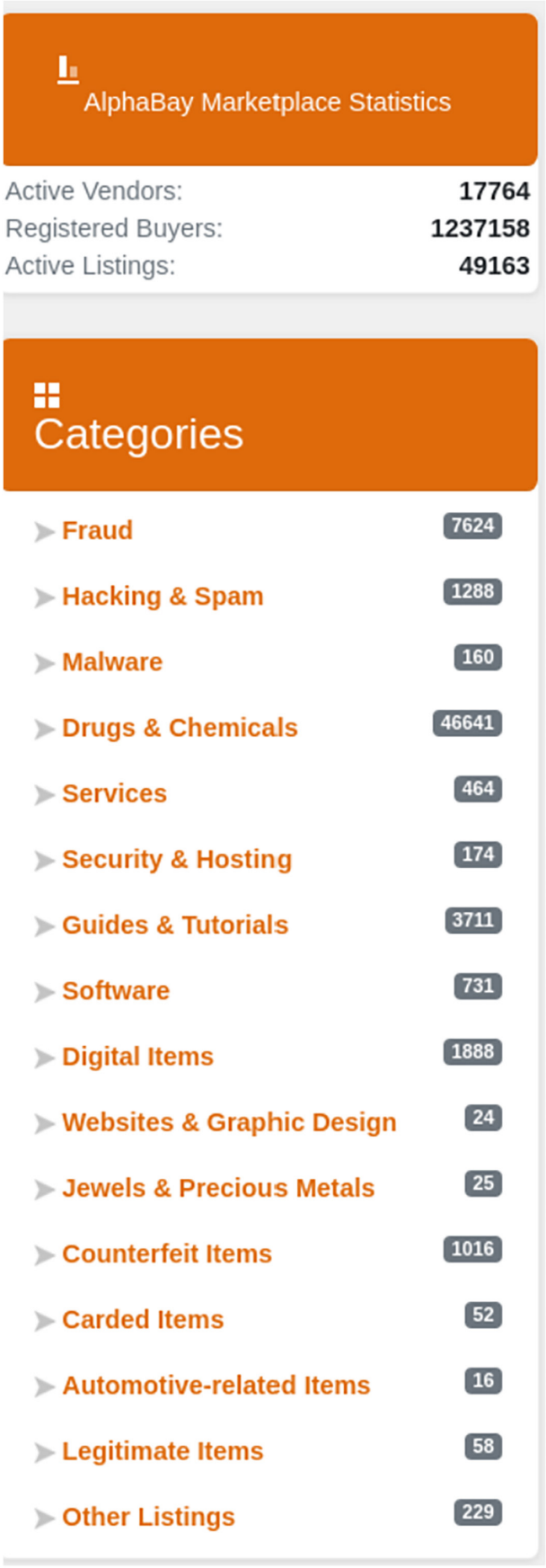


FIGURE 1 AlphaBay marketplace statistics and categories (as of January 2023).

3 | MAKING THE UNKNOWN KNOWN: METHODS FOR REVEALING THE DNM FENTANYL TRADE ON TOR AND I2P

This section provides a summary of the data collection and analysis methods used in this study. We begin by describing the way data

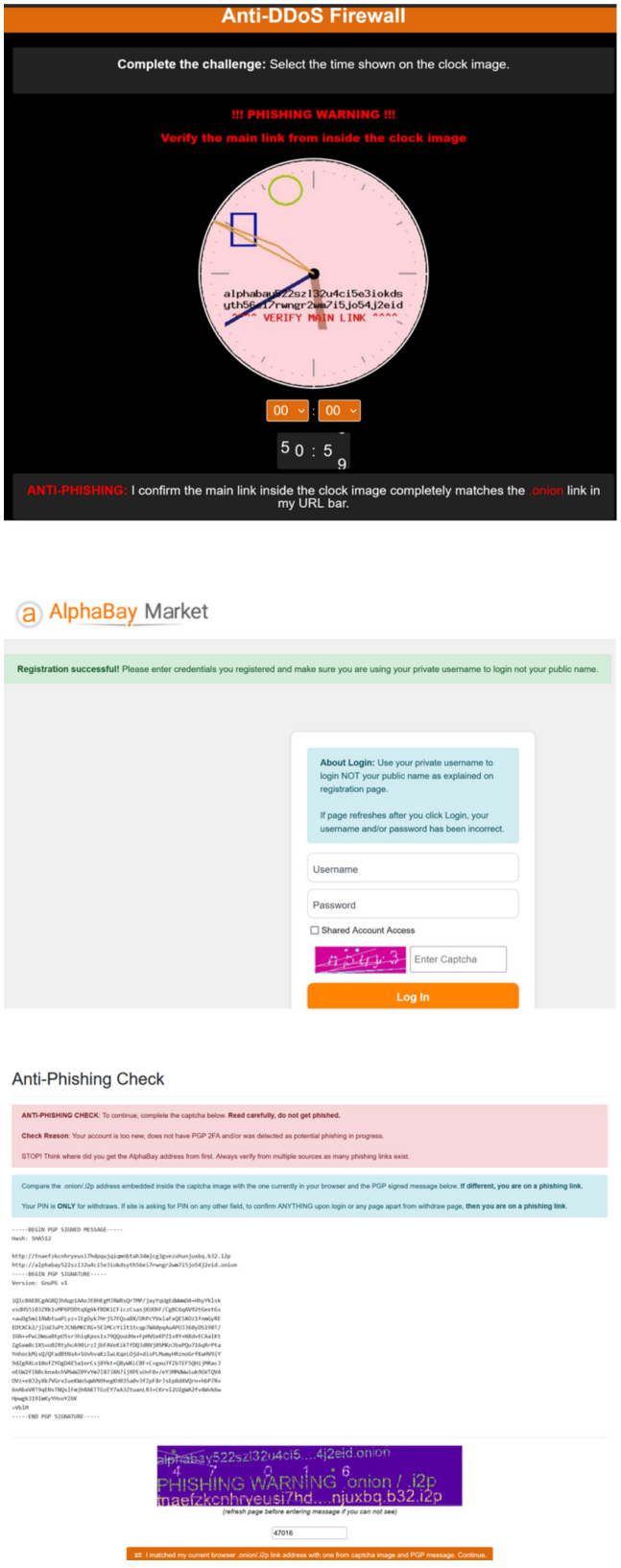


FIGURE 2 (a) Anti-DDoS firewall. (b) AlphaBay login screen. (c) Anti-phishing check.

was collected from AlphaBay's I2P website, including the installation and configuration process for I2P. We then describe our process for scraping data from AlphaBay and creating a searchable database of this marketplace's data. Finally, we discuss the qualitative methods used in our study, including document analysis, review of historic DNMs, interviews, conducting expert interviews and a focus group, content analysis, and social network analysis. These qualitative methods were used to uncover and analyze AlphaBay fentanyl networks and map AlphaBay overt and covert fentanyl vendors, as well as predatory vendors.

3.1 | Configuring systems for I2P

Collecting data from an I2P website requires the installation of compatible I2P software designed specifically for a user's operating system. This software and the setup instructions for each operating system can be found on the official I2P project website (https://geti2p.net/en/). Unlike onion sites, a pre-configured web browser is not provided by the official I2P project to access websites on the I2P network. Once the I2P software was installed, we configured the proxy using the two options available. Presumably, using both proxy installation methods does not have a negative effect on the use of I2P; however, each method has certain advantages. Users are not required to use both proxy configuration methods. The method chosen should be based on the user's comfort level with browser and proxy configurations, and the changes a user is allowed to make to the system based on their operating system account's privilege level. The first option available was using the manual provided by the official I2P project to configure the browser settings. This process was tedious and does not always achieve the desired outcome. The alternative was to utilize a free browser extension available for both Google and Firefox in their respective extension stores. The researchers implemented a number of these free extensions for accessing I2P websites, and found that these extensions worked well on Google Chrome, Chromium, Mozilla Firefox, and the Tor Browser. All the extensions made for Google Chrome and tested were installed and function on the Chromium browser. The extensions created for Mozilla Firefox were also installed and function on the Tor Browser. Finally, once the extensions have been added and the browser is configured, we configured our network's proxy.

The official I2P project provided configuration instructions for both HTTP and HTTPS. However, we found no marketplace using HTTPS and chose not to use this configuration option. Once the network proxy was configured, we tested a number of the I2P extensions and browser configurations. Our test showed that while using several extensions, some browsers could only access I2P websites when the proxy network configuration was active. In contrast, we observed that other extensions with the ability to specify how the browser should interrupt domains and protocols could easily distinguish between clearnet, darknet, and I2P websites. For our research, we preferred keeping the browsers configured for accessing I2P separate from other uses, and we selected extensions that limited access to non-I2P pages. While it is possible to collect data from the darknet marketplace using the Tor network, to combat DDoS attacks these marketplaces have

implemented layered security protocols that are not needed or implemented on the I2P versions of these marketplaces. When using the I2P version of most marketplaces, the only requirement was to login to a DNM or to re-verify a user after the session timeout by entering a user's credentials and the letters displayed in a static captcha. This allows researchers to use a headless version of an automated captcha program without using a browser to interact with the website directly. Currently, Tor marketplaces normally have multiple DDoS dynamic captcha features that need to be answered correctly before a user can enter their login credentials. The lack of these security protocols on I2P DNM websites creates an environment that removes some of the obstructions to automated data collection.

3.2 | DNM data collection

Collecting data from a darknet marketplace hosted on I2P was similar to the process used to collect marketplaces hosted on Tor, some minor but notable differences were observed during the collection process. The first step in the data collection process was identifying DNMs with a functioning I2P website. One way of ascertaining whether a marketplace has an I2P address is checking a marketplace's Tor or onion link sites and marketplace aggregator sites (e.g., Darknet stats, Darktrain Express, Tor Taxi, or Dark.fail). While choosing a marketplace, we observed that several marketplaces (e.g., Tor2Door, AlphaBay, and Incognito) currently have I2P websites. However, operating practices and other factors may prevent a user from accessing the marketplace briefly and intermittently throughout the day.

For our research, AlphaBay was chosen as the marketplace for observation and analysis. The reason for its selection was the very stable uptime we observed during the observation period compared to other marketplaces which were affected by several observable intermittent downtimes during the day. For example, it was noticeable that between Friday afternoon and Monday morning, except for AlphaBay, many of these I2P marketplaces were offline for an extended period. Additionally, Tor2Door, during 2022, had extended downtime periods and was flagged by marketplace aggregators as potentially exit scamming. A single collection of a large marketplace could take days or weeks because of the built-in session timeout period, and marketplace downtime could extend this time significantly. Due to these factors, we decided to collect and examine AlphaBay, which appeared to have very few downtime periods during the data collection phase and was not flagged by marketplace aggregators for unusual marketplace activities.

The data collection process started with accessing the marketplace using a virtual machine configured to access I2P sites utilizing the Tor browser. Our first observation when accessing AlphaBay was that the I2P site did not have the DDoS protection page, which has become standard for Tor marketplaces. An examination of other DNMs also revealed that while the CAPTCH login pages were still present, none of the marketplaces had a DDoS protection page on their I2P sites. Next, we tested user credentials created using the Tor version of AlphaBay and found that these worked without any issues. We then examined the code structure on the marketplace pages and found no noticeable differences between the Tor and the I2P marketplace webpages. The researchers then tested the patterns used to identify data stored on the pages classified as category listing pages, product pages, and vendor pages, which revealed that for data collection and parsing, there were no differences between the I2P marketplace website and Tor marketplace website webpages. Like all data collection processes, understanding the marketplace structure allows for the program's collection and parsing of the data uniformly. The program used to collect the data was written in JavaScript, while the data parsing program was written in Python. While it is possible to write both programs in either language, the JavaScript program was significantly more efficient at performing several tasks faster and less error-prone for data collection. We also found that the data parsing programs were simpler to program using Python; hence the reason for the two programs being built in separate languages. Efficiency and error-free collection and parsing are critical given that the data collection program collects over 100,000 files per marketplace collection, while the parsing program generates over 175,000 records in the different tables from the marketplace collection.

Once we gained access to the marketplace using the I2P network, we used the category weblinks as the starting point for our data collection program. Using the unique pattern for the category weblinks, we collected all the category pages and stored these HTML pages as text files. The researchers then collected the product and vendor pages using the weblinks collected from the category pages. These weblinks are also identified by the patterns unique to vendor and product weblinks. The vendor and product HTML pages were also stored as text files, and screenshots of these pages were saved as PNG files. We found that the category pages needed to be collected first, the product pages second, and the vendor pages last. While it would appear that there is no advantage to collecting product pages before vendor pages, we found that some of the more questionable items are removed by the site administrator or vendor hours or days after being listed. Therefore, if the objective is to maximize the collection of items on the DNM, the product page collection should be prioritized.

Once the data was collected, a parsing program designed specifically for the AlphaBay DNM extracts the data stored in the HTML text files. The program read and parsed the data stored in the HTML text files. The program can identify the type of page (vendor, category, or product) by particular data, which is unique to each page and present in all files of these types. This pattern matching was implemented by using regular expressions to ensure the HTML page is from the AlphaBay marketplace, then identifying the particular page type. Once the correct page type was determined, the data stored in the text file was sent to the correct module for data extraction and placement in the right database table. In this article, we present our findings relating to the identification of the illicit fentanyl trade on AlphaBay.

3.3 | DNM data analysis

We analyzed DNM data by conducting document analysis, a review of historic sites, expert interviews, a focus group, content analysis, and social network analysis. Each of these methods are explored below.

3.3.1 | Desk research, DNM historic site review, interviews, and focus group

First, we carefully reviewed government reports, academic literature, newspaper articles, and online forums to better understand the fentanyl trade. We then conducted an in-depth review of historic DNM sites (i.e., Silk Road, Silk Road 2.0, Middle Earth, Pandora, Agora, and the first iteration of AlphaBay) made available from Branwen et al. (2015) [88]. This in-depth review enabled us to identify the evolution of the fentanyl trade on DNMs and the common vocabulary utilized by users of these sites across DNM platforms. We then cross-checked our findings with the findings we obtained during our expert interviews and focus group with seven criminal justice practitioners who had extensive knowledge of drug trafficking on DNMs (e.g., Federal Bureau of Investigation, Drug Enforcement Administration, and National Cyber-Forensics and Training Alliance). The goal of these discussions was mainly to verify and substantiate the information we obtained from our own desk research on DNMs and to identify the top DNMs where drugs, specifically fentanyl, was bought and sold [69].

3.3.2 | Content analysis

Second, recognizing the limitations of quantitative approaches, we conducted a qualitative content analysis of the collected AlphaBay data, to explore and identify unique covert language used by vendors. We chose qualitative content analysis because we wanted to understand the fentanyl trade and vendor language used on DNMs, which is an understudied area of research that cannot be captured using quantitative methodologies.

Our approach involved reviewing all AlphaBay categories, product listings, vendor profiles/descriptions, and feedback. We did not simply review opioid listings to identify synthetic opioids because our desk research and review of historic sites revealed instances where illicit drugs were placed in the wrong categories (i.e., not the correct drug category and/or in a different category altogether); this could be purposeful to avoid unwanted attention, accidental, or because of a lack of knowledge of the larger drug class of the illicit drug. We thus comprehensively reviewed AlphaBay data to first identify the explicit use of the words *fent*, *fentanyl*, and misspellings of these words. We discounted instances where fent free, no fent, or another statement was made indicating that fentanyl and/or its analogues were not for sale, with one exception: when buyers mentioned in their feedback of a product and/or vendor that the substance they purchased was adulterated with fentanyl and not as advertised. The latter finding of fentanyl is not listed as the overt sale of fentanyl but as a predatory listing as the vendors did not inform buyers that the substance contained fentanyl. We subsequently reviewed our data for specific covert words (see Table 1 for these words). As a quality

TABLE 1 Sample of covert words identified on AlphaBay.

SNA category	Covert words identified on AlphaBay
Roxy*	roxicdone/roxy/roxycodone/roxy*** oxicodone** oxycodone** m30** blues** press** 30mg** pressed**
M30	m30*** oxy** oxycodone** reds** synthetic** opiate**
Mexico*	mexican/mexico*** blue** m30** m30s** blues** popcorn** press** pressed** cartel** oxycodone** synthetic** opioid** mexi-30** 30mg** china** white**
China	china*** white** heroin** number 4** press** m30** oxy** pressed** oxycodone** superman** 90/10** poppy/synthetic** mix/synthetic** synthetic** white/synthetic** cw**
Synth*	synth/synthetic*** el nino** superman** heroin poppy** h** m30** china** lion** white**
Popcorn	popcorn*** oxycodone** m30** pressed** m30s**
Smackers	smackers*** m30** super** oxycodone** press** oxy** 30s** oxyocodone** pressed**
Press	press/pressed*** m30** oxycodone** m30s** oxy** 30s** 30** milligram** 30mg** mg** synthetic** opiate** (m30) **
Blue*	blue/blues *** m30** oxycotin (s) ** oxycodone** 30mg** oxy** press** smackers** super** popcorn** pressed** synthetic** opioid** 30s**
Purple	Purple*** china** white** fent** synthetic** heroin**
Zeta	Zeta*** oxycodone** m30s** press zetas**
Sinaloa	Sinaloa*** press** m30**cartel** pressed** m30s**
30	30 mg/30s*** oxy** oxycodone**
Cartel	Cartel*** m30** blue** oxycodone** oxy** press** pressed** m30s** popcorn**super** smackers**

Note: ***Primary covert words identified in listing. **In addition to the primary covert words in listing, the listing includes one or more of these additional terms. *Multiple variations for primary covert word in listing.

check for each result that contained more than one of the existing or new code words, we reviewed each result. While this was a very time-consuming task it was necessary to determine if it was plausible that fentanyl was sold and/or fentanyl was in the product sold. Any listings with one or more of these covert words were further reviewed and new covert words were identified. We cross-checked any new words encountered (i.e., words that were not identified in our literature review, by criminal justice practitioners in our expert interviews and focus group, and not included in the DEA's list of fentanyl code words [89] and other government reports) with clearnet searches (including forums like Reddit) to determine if these words were associated with fentanyl (see Table 1 3and the next section for our findings).

To ensure intercoder reliability, we coded content separately, and then reviewed and discussed the codes to verify consistency in coding and resolve any disagreements. With respect to the buyer and/or seller feedback, two coders reviewed the feedback for 2132 listings with an intercoder reliability score of 0.976 (calculated using the Holsti method). The authors conducted a final review and quality check of codes.

3.3.3 | Social network analysis

Third, using AlphaBay data, we conducted social network analysis (SNA) to detect AlphaBay fentanyl networks and map data about AlphaBay fentanyl vendors, including predatory vendors who sell drugs adulterated with fentanyl without warning or advertising that the drugs contain fentanyl. SNA was chosen because it captures the social context of interactions [90] and measures observable relations (i.e., informational or material links) between sites (i.e., loci within which human interaction occurs). It enables us to "connect the dots" by mapping out and measuring complex (and at times, covert) organizations and/or groups. Particularly, we used SNA to not only identify the overt sale of fentanyl but also to identify covert fentanyl sale and connections between buyers and fentanyl vendors on this DNM.

There are various programs available to analyze social networks. In this study, we used Gephi 0.10 software. This program, among other available software, was chosen due to its open-source access, computational efficiency, and state-of-the-art features. Using Gephi, we constructed bipartite networks that linked vendors to trade listings across the AlphaBay database. In this database, we created edge lists using Microsoft Excel that connected vendors to the concentration of adulterated substances as well as covert and overt fentanyl sales. Once created, these edge lists were exported from Microsoft Excel in comma-separated value (csv) format and imported into Gephi (version 0.10) as directed networks. Once imported, we analyzed the association of code words to that of 167 different vendors across 1422 total listings. To protect the privacy of subjects, a random number generator was used in the assignment of pseudonyms to vendors listed on the network graphs.

Using the Yifan Hu Proportional layout, sociograms were created for five separate network analyses, including the sale of overt fentanyl (Figure 3), predatory vendors and the sale of adulterated products (Figure 4), sale of covert fentanyl (Figure 5), sale of covert and overt fentanyl, and predatory listings with drugs adulterated with fentanyl (i.e., fentanyl networks) (Figure 6), and the sale of covert and overt fentanyl with predatory vendors (i.e., all networks) (Figure 7). In these graphs, nodes were labeled and sized in accordance to ranked degree centrality. Linkages between nodes were then color-coded and edge thickness was made proportional to the number of associations between nodes. The sociograms, which were exported in Portable Document Format (PDF), are discussed in the next section.

4 | RESULTS

Overall, we detected the overt and covert fentanyl trade on AlphaBay. Regarding the overt trade of fentanyl, unlike many historic DNM sites, fentanyl was no longer a subcategory of opioids. On AlphaBay, we identified five vendors who explicitly offered this illicit drug in either the product listings, category listings, or vendor profile/descriptions (Figure 3). These vendors overtly sold fentanyl patches (using the words "*patch*" and "*patches*") (for select examples of feedback on listings with overt fentanyl, see Table 2 below).

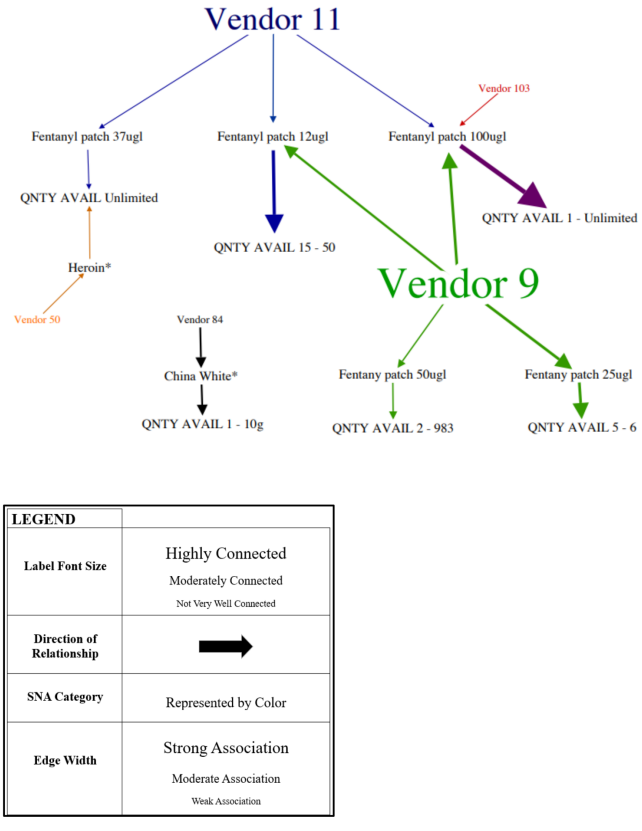


FIGURE 3 Overt fentanyl sale.

TABLE 2 Select examples of feedback for listings with overt fentanyl and products adulterated with fentanyl.

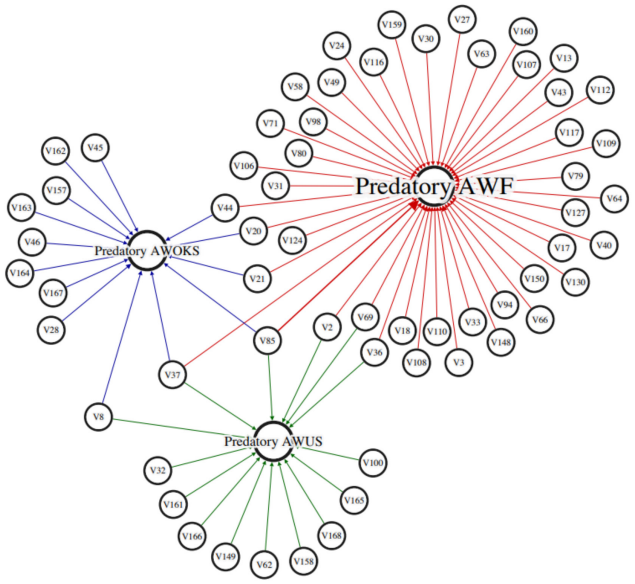
Vendor	Buyer	Listing	Feedback	Type of listing
Vendor 11	n****0	Fentanyl patches 12ug (Sandoz)	professionally packed with very excellent stealth. Fast delivery. and He added an extra one, Thanks!	Overt fentanyl
Vendor 9	p****8	Discount: Fentanyl patch 50×12ugl Sandoz/Teva 150 Euro	Top 10/10	Overt fentanyl
Vendor 148	p****4	Supe Smackers M30 Oxycodone	Sniffed a bump, felt legit, however tested positive for Fent on five different test strips against a control. Please be careful	Adulterated with fentanyl
Vendor 85	n****u	FE APPLE BATCH NO4 HEROIN FENT FREE	Just 4 days T2D, so very fast. Staff was average. With a marquis test the solution turned purple, so there is definitely H in there. However, it initially went orange, meaning there might be some fent. The potency is what you would expect from proper H though, so not too concerning, but start small at first to be safe… Effects are good: produces a nice nod at higher doses, and at lower doses the product is actually quite stimulating and euphoric. High quality product	Adulterated with fentanyl
Vendor 117	b****2	X10 Oxycodone M30 Mexican Supply	This shit will knock u the fuck outM30 was strong i believe it might be fent based on the way it knocked me the fuck out and i didnt feel like getting up the next day I had a goood sleep knocked out but it satisfy the craving	Adulterated with fentanyl
Vendor 85	y****e	ESCROW 20 CARTEL PRESSED M30S	I test them with testing strips for fenty and they came back positive made a dipsute with the vendor he say they tested them professional and they dont refunded the test strips so I said fuck it and ate a little piece bc i spend my money then i didnt feel anything so i ate almost a whole one then I feel pretty good. the shipping was fast and they looked solid I just worried Im risking my life for a high so just beware	Adulterated with fentanyl

The above network graph (Figure 3) presents the association between de-identified vendors and the sale of overt fentanyl products. This network involved 33 listings that were linked to 5 different vendors. Of these actors, Vendor 9 was found to have the highest number of listings in the network (20). The next highest concentration of overt listings was that of Vendor 11 (6) followed by Vendor 103 (2). These vendors were found to sell various forms of fentanyl patches in different available quantities (*qnty avail*). For instance, Vendor 9 was linked to four different fentanyl patches including that of 12ugl, 25ugl, 50ugl, and 100ugl (note: these patches provide 12, 25, 50, and 100 mcg doses of fentanyl, respectively). For these listings, there were available quantities that ranged from 1 to an unlimited number of patches. The remaining two vendors listed the availability of fentanyl for sale in their product descriptions (as opposed to their product or category listings). For this reason, we linked these vendors to the listings that included the sale of fentanyl in the product descriptions. Specifically, Vendor 84 was linked to four different listings of China White that ranged from 1 to 10 grams. Finally, Vendor 50 was linked to a heroin listing that referenced an unlimited available quantity of the product.

Our review of AlphaBay data also provided confirmation of the presence of code words associated with fentanyl, which were identified in available literature, government reports, and by criminal justice practitioners as indicating the presence of fentanyl (see Table 1 above for sample of words). A case in point is the sale of M30s. Law enforcement and even users of this DNM site (and other sites) verified that M30 listings usually have fentanyl (e.g., on AlphaBay, user c****s stated, "I've ordered m30's for 2 different people from … [*******] and both say his quality is unmatched by any other pressed pill. I assumed they were fent…"). There were, however, vendors who stated no fentanyl in their M30 listings. Nevertheless, we did find instances in reviewers' feedback where vendors stating that they had no fentanyl in their listings were accused of adulterating substances that they were selling with fentanyl (e.g., AlphaBay, buyer h****w, stated "Pills were pressed with Fent despite being advertised as pharmacy authentic"). Buyers identified fentanyl either from using fentanyl testing strips which indicated the presence of fentanyl in the substance purchased or stated that the substance was adulterated with fentanyl because of the way it made them feel or at least they believed it was adulterated with fentanyl (e.g., AlphaBay buyer, y****2, "Dope tested positive for fent, but I feel somewhat responsible given that china white usually implies fent…"; see Table 2 for some examples of listings where buyers claimed substances were adulterated with fentanyl). In fact, we found listings where buyers

tested their purchase of MDMA, Xanax, cocaine, methamphetamines, and opioids like heroin and found that these drugs were adulterated with fentanyl (e.g., AlphaBay buyer, e****s, "Definitely not ketamine…tests positive for FENTANYL!"; AlphaBay buyer, d****f, "looked like purple molly…but when I used a fentanyl strip it tested positive twice…"; AlphaBay buyer, t****y, who purchased cocaine, stated "tests positive for both meth and fent…"). The network of predatory AlphaBay vendors that we identified based on buyer's feedback is included in Figure 4.

The above network graph (Figure 4) presents the association between de-identified predatory vendors and the sale of adulterated listings, which included drugs containing fentanyl (i.e., *adulterated with fentanyl* or *AWF*), other known illicit substances (e.g., amphetamines) (i.e., *adulterated with other known substance* or *AWOKS*), or unknown illicit substances (i.e., *adulterated with unknown substance or AWUS*; substance is unknown because either buyer did not test the substance or only tested for limited known substances, such as methamphetamine and fentanyl). Of 138 total listings (identified from the feedback), 95 (69%) were identified as being adulterated



LEGEND	
Label Font Size	Highly Connected Moderately Connected Not Very Well Connected
Direction of Relationship	➡
SNA Category	Represented by Color
Edge Width	Strong Association Moderate Association Weak Association
Predatory AWF	Adulterated with Fentanyl
Predatory AWUS	Adulterated with Unknown Substance
Predatory AWOKS	Adulterated with Other Known Substance

FIGURE 4 Predatory vendors' sale of adulterated products: Listings with products adulterated with fentanyl (AWF), adulterated with other known substance (AWOKS), and adulterated with unknown substance (AWUS)].

with fentanyl. These listings were associated with 44 different vendors. Of those actors, Vendor 85 was found to have the highest concentration of listings (19) that were adulterated with fentanyl. The next highest concentration of listings involved Vendor 148 (6), Vendor 36 (5), and Vendor 31 (4). In comparison, the average number of associations between vendors and listings that were adulterated with fentanyl was 2.2.

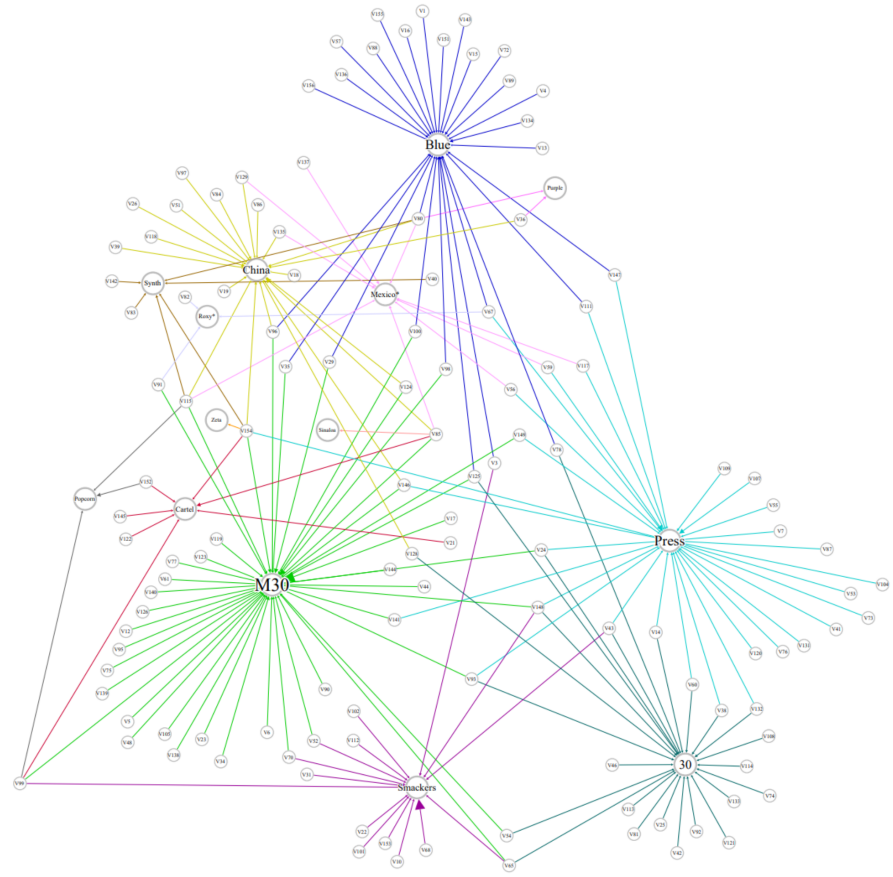
The examination of other listings resulted in the identification of 24 (17%) that were adulterated with an unknown substance. There were 15 different vendors associated with these listings. Of these actors, Vendor 8 had the most listings of drugs containing one or more unknown substances (7). This actor was followed by Vendor 100 (3) and Vendor 85 (2). The remaining vendors all had one listing. The average number of linkages to adulterated drugs with an unknown substance was approximately 1.6. The remaining listings (19) were identified as being adulterated with other known substances (these substances were identified through testing). These listings were associated with 14 different vendors. Of these actors, Vendor 28 had the most listings of drugs containing a known substance (4). This actor was followed by Vendor 44 (2) and Vendor 8 (2). The remaining actors all had one listing of a product adulterated with a known substance. In comparison, the average number of associations between vendors and listings that were adulterated with a known substance was 1.4.

Regarding the use of covert words by vendors, we identified other terms – not identified in our original literature review and historic DNM site research – that were associated with the sale of fentanyl which we have included in Table 1. For example, the word *purple* was used in conjunction with words that have been identified as linked to the sale of fentanyl (e.g., "*synthetic*," "*synthetic heroin*," "*China White*," "*Mexican Blues*," "*Blues*," "*press*," "*pressed*," etc.). The word *popcorn* was also used in listings along with other code words associated with fentanyl (e.g., "*Oxycodone M30 Popcorn*" and "*Blues Popcorn M30 presses*"). Buyers confirmed its link to fentanyl (buyer f****r, "…its like a Fetty (M30 fent Mexican cartel presses that taste like popcorn) had a baby with real pharma Roxicodone) so its not just straight popcorn taste, it has the oxy taste too" [sic]; buyer h****l, "Classic cartel popcorn blues…they smoke great probably fent but they never said it wasn't…" [sic]; buyer g****3 stated that the "Oxycodone M30 30mg Cartel Popcorn" purchased, "[t]ested positive for fentanyl").

In addition, the word *smacker* was used in conjunction with other known code words (e.g., "M30 super smackers", "Super Smackers OxycodoneM30," "Super Smackers 30s," "M30 Blues Super Smackers," "Supe Smackers M30 Oxycodone Pressed," "Pressed Oxycodone M30…These pills SMACK HARD!"). We did find the word *smackers* in feedback. For example, one buyer stated "Fent based Oxys. Smackers. Recommended." Moreover, the words *cartel* (e.g., "Cartel M30" and Cartel Popcorn Press"), *Sinaloa* (e.g., "These are the famous M30s manufactured by the Sinaloa Cartel"), *Mexico* (e.g., "M30 Mexican supply," "pressed pills from Mexico," "Strength of Synthetic China that Mexico Produces," and "This is the most potent synthetic china white manufactured in Mexico") and *China* (e.g.,

"Synthetic heroin imported from China") were also used. Buyers' feedback for certain listings with the word "cartel" included a few reviews mentioning fentanyl in those drugs (e.g., buyer y****e, "I test them with testing strips for fenty and they came back positive…" [sic]; buyer j****9, "I don't have to worry about getting cartel fent bombs…"; buyer t****5, "worth the extra money over the cartel smackers"). The word *cartel* was also used in category and product listings for other drugs (e.g., cocaine and methamphetamine) that various cartels and organized criminal groups are also known for selling. Nevertheless, when the code words we identified are used with other known terms (e.g., "M30 and press" and "*synthetic heroin*" and more combinations of words), it is possible that what is sold is fentanyl. The network of AlphaBay vendors that covertly sell fentanyl, which we identified based on the sample code words included in Table 1, is included in Figure 5.

Figure 5 presents the association between the sale of covert fentanyl and de-identified vendors. Of the 1046 total listings, 406 (39%) were associated with *M30* and 156 (15%) were linked to *Smackers*. The next highest concentration of covert code words included *Blue* (112), *China* (112), *Press* (106), and *Mexico** (44) (Mexico has an asterisk "*" because the words *Mexico*, *Mexican*, and *Mex* were used in listings; see Table 1). The remaining code words and associated listings included *Cartel* (36), *Popcorn* (28), *Synth* (20), *Purple* (14), *Sinaloa* (6), *Roxy** (5) (Roxy has an asterisk "*" because the words *roxy blue/s*, *oxycodone*, and *roxycodone* (mispelled) were used in listings; see Table 1), and *Zeta* (1). The 1046 total listings were linked to 98 different vendors. Of these actors, Vendor 17 posted the most listings (115). Of these connections, all (115) involved *M30*. The next highest concentration of code words involved Vendor 68. This vendor was associated with 103 product listings that involved *Smackers*.



LEGEND	
Label Font Size	Highly Connected Moderately Connected Not Very Well Connected
Direction of Relationship	➡
SNA Category	Represented by Color
Edge Width	Strong Association Moderate Association Weak Association

FIGURE 5 Covert fentanyl sale.

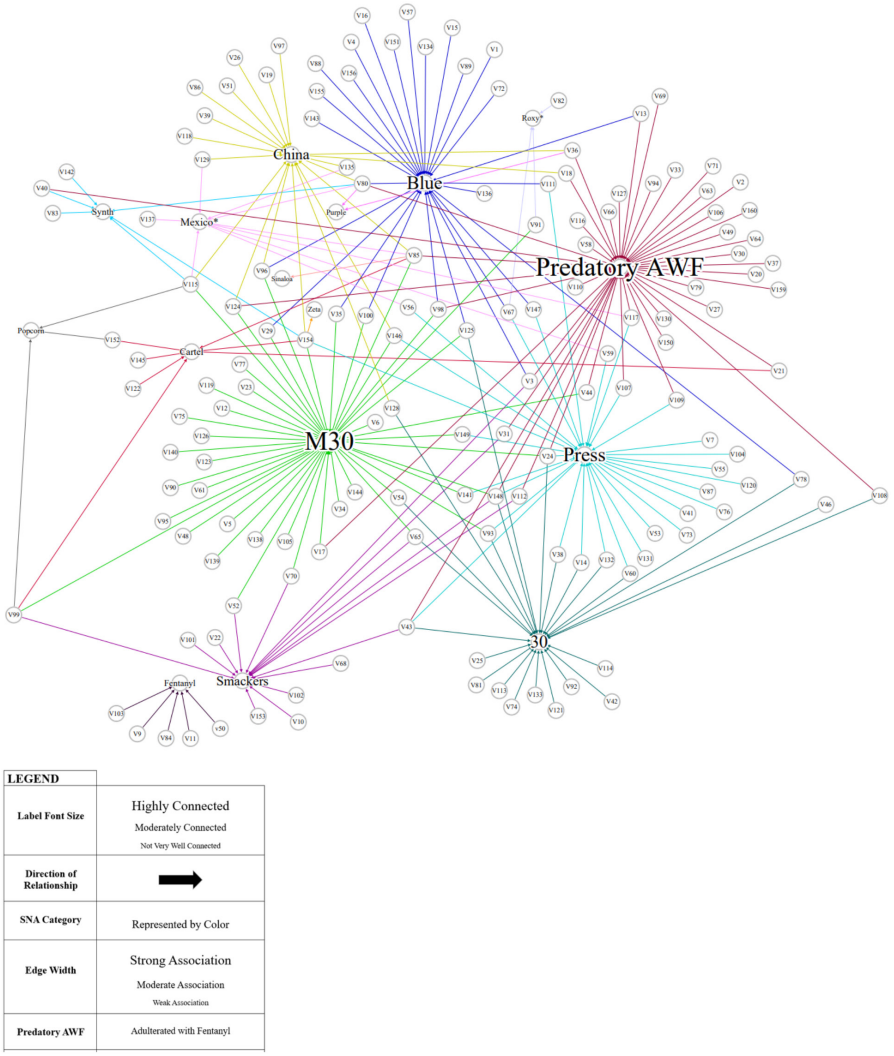


FIGURE 6 Fentanyl network: Overt and covert fentanyl sale, and predatory listings with products adulterated with fentanyl.

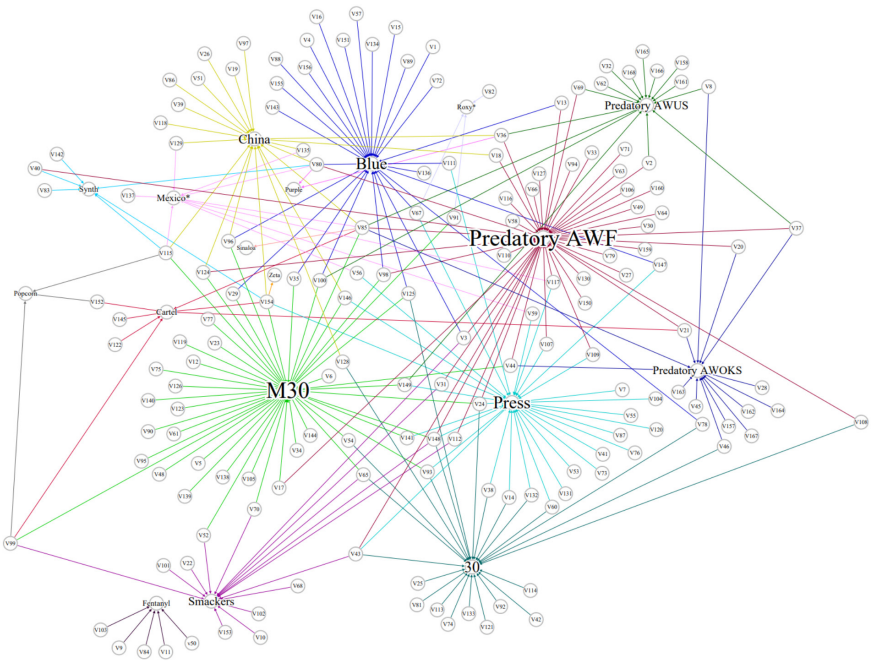
The remaining highest concentrations of listings involved Vendor 85 (76) and Vendor 98 (65). In comparison, the average number of connections to listings across the network structure was approximately 10.7. The vendor with the most unique code word associations was Vendor 154. This vendor was connected to 6 different covert SNA categories including that of *Cartel*, *China*, *M30*, *Press*, *Synth*, and *Zeta*. In comparison, the average number of covert code words that the vendors were associated with across the network structure was approximately 1.5.

The entire fentanyl network we identified on AlphaBay is depicted in Figure 6. This network graph combines Figures 3 and 5 and the adulterated with fentanyl substances listed on Figure 4. Altogether, this network graph presents the association between de-identified vendors (152) and AlphaBay listings (1379), including vendors that overtly and covertly sold fentanyl on this DNM site and predatory vendors who sold drugs adulterated with fentanyl.

Finally, to provide a comprehensive view of our findings, Figure 7 depicts all networks we identified on AlphaBay (covert, overt, and predatory) as presented in Figures 3–5, and showcases the association between de-identified vendors (167) and AlphaBay listings (1422), including vendors that overtly and covertly sell fentanyl and predatory vendors that sold drugs adulterated with substances other than those advertised.

5 | DISCUSSION

Unlike prior studies that focused on the overt trade of fentanyl as indicated in the listings [44,68,72], we identified the overt sale of fentanyl outside of product listings and we identified covert listings of fentanyl on AlphaBay. In fact, we found few instances of the overt sale of fentanyl (less than previous studies [72,73]), when compared to the covert sale of fentanyl and sale of adulterated substances with fentanyl on AlphaBay. Like Broadhurst, Ball, and Trivedi (2020), who found fentanyl sold on the Dream Market DNM despite the site's fentanyl ban [44], we also found fentanyl sold on AlphaBay despite its ban of this illicit drug. The DNM ban on fentanyl and increased law enforcement attention to this drug has, at least in part, made fentanyl markets and networks more secretive and closed (i.e., less visible). Specifically, many vendors have stopped using the word *fent* or *fentanyl* in their product listings, category listings, product descriptions, vendor descriptions, and vendor profiles.



LEGEND	
Label Font Size	Highly Connected Moderately Connected Not Very Well Connected
Direction of Relationship	➡
SNA Category	Represented by Color
Edge Width	Strong Association Moderate Association Weak Association
Predatory AWF	Adulterated with Fentanyl
Predatory AWUS	Adulterated with Unknown Substance
Predatory AWOKS	Adulterated with Other Known Substance

FIGURE 7 All networks: Covert and overt fentanyl sale and predatory vendors.

Instead, we observed numerous vendors introducing various code words to indicate (or signal) that fentanyl is sold. Unlike previous studies, we used qualitative methods to identify the covert language used by fentanyl traffickers. The covert language of fentanyl traffickers on DNMs is not easily detectable and required the authors to analyze scraped AlphaBay data systematically to carefully identify these words. Even though it is possible that fentanyl is sold by vendors who used these code words, barring confirmation from buyers (in, for example, the feedback), which we did not frequently encounter, or the controlled delivery of the item to test the quality of the drug, we cannot say with certainty that fentanyl is sold. We can only say that it is plausible that fentanyl is sold where we identified more than one code word associated with fentanyl. The more code words used, the greater the possibility that fentanyl is sold. Recently, a vendor was arrested that operated on several DNMs, including AlphaBay. This vendor (narco710) was identified as selling Oxycodone M30 pills. In the criminal complaint against the vendor [91], it was mentioned that "*cartel M30s*" were covert words used to describe counterfeit oxycodone and laboratory tests of the drugs that law enforcement purchased from this vendor through controlled drug delivery confirmed the presence of fentanyl in the drugs. Law enforcement also identified "*synthetic China*" and "*China white*" as covert words used to describe "synthetic heroin usually mixed with fentanyl or other similar synthetic opioid drugs" (p. 19) [91]. Drugs purchased by law enforcement from listings using these words confirmed that the drugs were adulterated with fentanyl [91]. In our dataset, we had identified this vendor as a likely seller of fentanyl based on the use of several commonly used covert words in his listings (i.e., "*cartel*", "*China White*", "*pressed*", "*synthetic*", and "*M30*").

Some of the new words and the words that were already identified by law enforcement agencies, in the literature, and government reports in isolation do not alone point to the sale of fentanyl. For example, the word "cartel" was also used in category and product listings for other drugs (e.g., cocaine and methamphetamine) that various cartels and organized criminal groups are also known for selling. The word purple was also used in category and product listings, as well as feedback. While this was listed as a code word for marijuana (DEA, 2018), and we found it used in marijuana listings, we cross-checked this information with clearnet sources and found that U.S. law enforcement agencies' press releases included references

to purple fentanyl [92] and "popcorn fentanyl" was included in a 2019 document from the Ontario Provincial Police [93].

Additionally, our findings, similar to the findings of U.S. law enforcement and government agencies [6], revealed that China and Mexico remain source countries for fentanyl (with Mexico playing a more prominent role) and are included as code words in drug listings (e.g., China, Mexico, Mexican, etc.) to confirm sources of the products. Mexican organized criminal groups were also mentioned by AlphaBay vendors, particularly the Sinaloa cartel and Los Zetas.

We further observed that vendors either simply do not report that their products contain fentanyl or falsely claim that their products do not contain fentanyl. Because fentanyl is much cheaper to produce, vendors may fail to report fentanyl in their products and/or falsely claim that their drugs are fentanyl-free. Unlike other fentanyl studies, we identified these vendors on AlphaBay, which we labeled as predatory vendors. We identified numerous predatory vendors who sold drugs that contain fentanyl. Vendor narco710, for example, was identified as a predatory vendor (e.g., buyer f****y of "New 1 GRAM F550 SYTHETIC CHINA WHITE", "this was crap. had to call paramedics due to fent in this shit…"). We identified predatory vendors who sold drugs adulterated with other known substances and unknown substances (e.g., buyer a****m of "7G COCAINE (HIGH QUALITY)" said: "Fast shipping. Good stealth. Past Morris reagent, but turned orange on the Marquisand Liebermann, so likely cut with amphetamines…"; buyer g****k of "ketamine s-isomer sugar (1g-225g) (us-us)" said, "…Reagent testing indicates POSSIBLE cut/analog (maybe DCK?) but is positive for K…").

The results of our study can provide much needed insights into the fentanyl trade on DNMs, which contributes to the ongoing opioid crisis around the world and poses significant risks to public health and safety. The results of our study can inform research and criminal justice practice by providing a better understanding of I2P (and Tor) DNMs and information on how to scrape data from multihomed DNM sites and build a database of DNM data, the latter of which can be used to identify fentanyl sales and networks, key actors and major players in the network, and the tactics and methods of operation of these fentanyl networks. While it is understood that we cannot make specific claims that DNM listings purporting to be fentanyl or listings containing code words for fentanyl, are indeed fentanyl, this methodology can inform resource allocation to target the most serious threats with U.S. criminal justice operations aimed at confirming the sale of fentanyl and targeting the most serious fentanyl DNM vendors.

The forensic value of scraping DNMs can be significant. Scraping allows law enforcement organizations to gather valuable intelligence on fentanyl vendors, staff, and other users of the DNM, and the DNM site. The scraping of data, such as monikers and PGP public keys, allow law enforcement to track fentanyl vendors over time and between different DNMs. This effort can be aided by using one of several Tor sites that allow searching a vendor's PGP public key and matching it to DNMs these vendors have operated on and the products they have sold in the past (examples of Tor sites that allow for searching a vendor's PGP public key across platforms include sites such as Darknet Trust and Recon). This method can assist in determining if the vendor has overtly sold fentanyl in the past and allow investigators to gauge whether it is probable that they have shifted to covert listings using code words. Moreover, the eventual seizure and forensic disk examination of computer equipment from fentanyl vendors are of high value, can confirm Tor browsing [94] and DNM activity [95], and data can be matched to databases compiled from the data scraping. This comparison allows law enforcement to link specific PGP encryption keys to specific dealers, allowing attribution of the dealers' volume and variety of drug listings, via their involvement in a specific DNM. Finally, the computer equipment can be forensically examined to retrieve cryptocurrency wallet addresses that may allow identification and location of illegal proceeds and funds held by fentanyl vendors, enabling their seizure by the government [96].

6 | LIMITATIONS

One main limitation to our research is that we can only identify vendors and products linked to fentanyl when covert words are used in category listings, vendor descriptions, product descriptions, and product feedback. Absent the purchase and testing of the drugs sold, we cannot verify that fentanyl is sold. Even the feedback from buyers may not necessarily be accurate. In fact, DNM vendors have accused buyers of falsely claiming that drugs contain fentanyl or other substances to scam the vendors and receive their money back. Vendors have also complained that competitors and buyers who support these competitors leave negative feedback about the vendors and their products (e.g., making false accusations about the quality of drugs to steal customers). Dispute resolution mechanisms on DNMs were designed to deal with issues like these, which arise between vendors and buyers.

A second limitation is that the new words are continuously being added to the list of words used by individuals in the fentanyl trade. The words we included in this paper were a sample of code words and were not exhaustive. We are frequently adding new code words to our list based on our critical and careful examination of fentanyl vendor and buyer interactions and DNM listings, product and vendor descriptions, vendor profiles, and vendor and product feedback.

A third limitation concerns the completeness of our dataset. We only used data collected from AlphaBay for the purpose of this study, so the findings are based on the analysis of one DNM site only. Moreover, on this site, the completeness of the data is only guaranteed for the day that the data is collected. If items are listed and then delisted (either by the vendor or the site administrator) without having a sale between the days the data was collected, there would be no record of the product ever being listed. It is unclear how often listing and unlisting happens. However, like any online marketplace, items being delisted are possible and presumably occur. Also, items listed covertly or overtly and sold through AlphaBay's messaging system, the vendor's vendor shop, or a third-party app would not be recorded on the marketplace. DNM researchers have hypothesized that high-volume transactions on DNMs are conducted using

a communication system that prevents the sale from having a public record [97].

A fourth limitation of our research is that we formed our methodology to collect (scrape) data from DNMs without having any direct contact with users of the sites. As our research was only "read only" it prevented us from gaining alternative forms of insight into the markets that would have been possible by interacting with DNM users. This limitation would not be experienced by law enforcement agencies conducting undercover operations.

A fifth limitation of our research is the rapidly evolving nature of DNMs on both the I2P and Tor networks. Participants of these networks readily exchange information to improve user experience, provide operational security against law enforcement and external attackers, and improve reliability of drug purchases [81]. The results of these efforts are constantly improving DNM sites, which strive to thwart attempts to scrape the sites, analyze DNM data, attack the sites, and counter the site's security mechanisms.

A sixth limitation of our research is the time of a marketplace sign-in session. AlphaBay allows users to stay logged into a single session for a maximum of 6 h. This prevented our program from running continuously. The effects of this interruption were minimized in two ways. First, when the session timed out, the marketplace sends the user back to the sign-in page to input their username and password again. Second, the program was designed to keep track of the links the program visited without collecting data and the current link being visited. The program could use the last link visited to pick up the collection process from the previous link visited if there was any interruption in the collection process. This particular feature has proven beneficial in minimizing the impact of disruptions to the collection process. Finally, the list of uncollected weblinks is used to attempt to collect the data the program could not collect due to a session timeout or a disruption in the connection between the virtual machine and the marketplace.

Overall, research on and investigations of DNMs present unique challenges, particularly due to the difficulty that I2P and Tor create in attributing users of DNMs to specific IP addresses [98]; the frequency that DNMs are decommissioned and taken offline; the frequency of new DNMs; the adoption of new code words for online fentanyl sale; security protocols employed by DNM sites, such as CAPTCHA systems and anti-scraping security techniques; and the structural differences between different DNMs and updates made to DNMs that result in the requirement of adjusting and updating DNM scraping techniques.

7 | CONCLUSION

The rate of increase of overdose deaths involving fentanyl shows a worrisome trend and illustrates the need for proactive measures to detect fentanyl in DNMs and expedite law enforcement intervention. Covert language used in the fentanyl trade is not easily detectable on DNMs. To assist in this endeavor, we used mixed qualitative methods to decode the language of fentanyl traffickers and detect fentanyl vendors on the AlphaBay DNM. Our study not only revealed covert words known by scholars, criminal justice practitioners, and government officials, but also revealed unknown and not widely known covert words associated with fentanyl (e.g., synthetic heroin, press, purple, cartel, and popcorn). We used these qualitative methods to learn the language used by fentanyl vendors, and identify and map hidden fentanyl networks on AlphaBay, as well as reveal predatory DNM drug vendors, who sold drugs adulterated with fentanyl, other known substances, and unknown substances. The results of our study can be used to inform strategies to detect fentanyl vendors, uncover hidden fentanyl networks, and dissolve these networks.

FUNDING INFORMATION

This work was supported by the U.S. National Institute of Justice [2019-R2-CX-0018].

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

ORCID

Marie-Helen Maras https://orcid.org/0000-0003-3428-4622
Kenji Logie https://orcid.org/0000-0001-7107-6510
Adam Scott Wandt https://orcid.org/0000-0001-8160-5519

REFERENCES

1. CDC. Fact sheet. Accessed May 15, 2023. https://www.cdc.gov/stopoverdose/fentanyl/index.html
2. NIDA. Trends and statistics: Drug overdose death rates. Accessed May 15, 2023. https://nida.nih.gov/research-topics/trends-statistics/overdose-death-rates
3. Goodison SE, Woods D, Barnum JD, Kemerer AR, Jackson BA. Identifying law enforcement needs for conducting criminal investigations involving evidence on the dark web. Santa Monica, CA: RAND Corporation; 2019 Document Number: RR-2704-NIJ.
4. Frisoni P, Bacchio E, Bilel S, Talarico A, Gaudio RM, Barbieri M, et al. Novel synthetic opioids: the pathologist's point of view. Brain Sci. 2018;8(9):170. https://doi.org/10.3390/brainsci8090170
5. U.S. Department of Health & Human Services. Determination that a public health emergency exists. October 16, 2017. Accessed May 13, 2023. https://www.phe.gov/emergency/news/healthactions/phe/Pages/opioids.aspx
6. U.S. Drug Enforcement Administration. 2020 national drug threat assessment. DEA-DCT-DIR-008-21. March 2021. Accessed May 10, 2023. https://www.justice.gov/usao-mdpa/page/file/1425276/download
7. Han Y, Yan W, Zheng Y, Zahid Khan M, Yuan K, Lu L. The rising crisis of illicit fentanyl use, overdose, and potential therapeutic strategies. Transl Psychiatry. 2019;9(1):282. https://doi.org/10.1038/s41398-019-0625-0
8. DEA. Accessed 21 May 2023. https://www.dea.gov
9. Volkow N. The epidemic of fentanyl misuse and overdoses: challenges and strategies. World Psychiatry. 2021;20(2):195–6. https://doi.org/10.1002/wps.20846
10. Dobson E. Fentanyl's rise on darknet markets (and how to stop it). Chicago Policy Review. 2020 Aug 10. Accessed May 21, 2023. https://chicagopolicyreview.org/2020/08/10/fentanyls-rise-on-darknet-markets-and-how-to-stop-it/
11. CDC. Other drugs. Accessed May 15, 2023. https://www.cdc.gov/drugoverdose/deaths/other-drugs.html

12. United States v. Wilson, No. 2:21-cr-00222 (Cal. C.D. Filed May 11, 2021).
13. United States v. Boukhanian, No. 2:21-cr-00228 (Cal. C.D. Filed May 12, 2021).
14. United States v. Lopez, No. 5:21-cr-00109 (Cal. C.D. Filed May 12, 2021).
15. United States v. Rodriguez, No. 8:21-cr-00078 (Cal. C.D. Filed Apr 28, 2021).
16. DOJ. Aaron Shamo's co-defendants sentenced in dark web narcotics distribution case. July 16, 2021. Accessed May 3, 2023. https://www.justice.gov/usao-ut/pr/aaron-shamo-s-co-defendants-sentenced-dark-web-narcotics-distribution-case#:~:text=Seven%20co%2Ddefendants%20were%20sentenced,month%20in%20a%20separate%20hearing
17. National Institute on Drug Abuse. Fentanyl drugfacts. Revised June 2021. Accessed May 10, 2023. https://nida.nih.gov/download/20630/fentanyl-drugfacts.pdf?v=7463664b4c495258862b99a803eb524d
18. Scholl L, Seth P, Kariisa M, Wilson N, Baldwin G. Drug and opioid-involved overdose deaths – United States, 2013-2017. MMWR Morb Mortal Wkly Rep. 2019;67(5152):1419–27. https://doi.org/10.15585/mmwr.mm675152e1
19. McKnight C, Des Jarlais DC. Being "hooked up" during a sharp increase in the availability of illicitly manufactured fentanyl: adaptations of drug using practices among people who use drugs (PWUD) in New York City. Int J Drug Policy. 2018;60:82–8. https://doi.org/10.1016/j.drugpo.2018.08.004
20. Tomassoni AJ, Hawk KF, Jubanyik K, Nogee DP, Durant T, Lynch KL, et al. Multiple fentanyl overdoses – New Haven, Connecticut, June 23, 2016. MMWR Morb Mortal Wkly Rep. 2017;66(4):107–11. https://doi.org/10.15585/mm6604a4
21. Rudd RA, Seth P, David F, Scholl L. Increases in drug and opioid-involved overdose deaths – United States, 2010-2015. MMWR Morb Mortal Wkly Rep. 2016;65(5051):1445–52. https://doi.org/10.15585/mmwr.mm655051e1
22. US. Attorney's Office. Central District of California. 7 federal criminal cases charge drug dealers who allegedly sold fentanyl that caused deadly overdoses in Orange County. 2022. Accessed May 17, 2023. https://www.justice.gov/usao-cdca/pr/7-federal-criminal-cases-charge-drug-dealers-who-allegedly-sold-fentanyl-caused-deadly
23. Daley J. Fentanyl is everywhere, and showing up in other illicit drugs. Colorado Public Radio (CPR) 2022. Accessed May 15, 2023. https://www.cpr.org/2022/06/20/fentanyl-is-everywhere-and-showing-up-in-other-illicit-drugs/
24. CWLA. CDC See increased drug overdose fatalities due to cocaine and fentanyl. Accessed May 15, 2023.https://www.cwla.org/cdc-see-increased-drug-overdose-fatalities-due-to-cocaine-and-fentanyl/
25. DEA Intelligence Report. Deadly contaminated cocaine widespread in Florida. Unclassified. DEA-MIA-BUL-039-18. February 2018. Accessed May 17, 2023. https://www.dea.gov/sites/default/files/2018-07/BUL-039-18.pdf
26. DEA Intelligence Report. Cocaine/fentanyl combination in Pennsylvania. Unclassified. DEA-PHL-BUL-061-18. Accessed May 17, 2023. https://www.dea.gov/sites/default/files/2018-07/BUL-061-18%20Cocaine%20Fentanyl%20Combination%20in%20Pennsylvania%20--%20UNCLASSIFIED.PDF
27. Patrick M. Three new Yorkers ordered cocaine from the same delivery service. All died from fentanyl. Wall Street Journal. 2022. October 23. Accessed 15 May 2023. https://www.wsj.com/articles/fentanyl-cocaine-new-yorkers-drug-delivery-service-all-died-11666526726
28. US. Department of Justice. Leader of drug delivery service responsible for three fentanyl poisoning deaths convicted. 2023. Accessed May 13, 2023. https://www.justice.gov/usao-sdny/pr/leader-drug-delivery-service-responsible-three-fentanyl-poisoning-deaths-convicted
29. Rosen LW, Barrios R, Lawrence SV. China primer: illicit fentanyl and China's role. Congressional Research Service. Updated December 8, 2022. Accessed May 17, 2023. https://crsreports.congress.gov/product/pdf/IF/IF10890
30. DEA Intelligence Report. Fentanyl flow to the United States. Unclassified. DEA-DCT-DIR-008-20. 2020. 2–3. Accessed May 18, 2023. https://www.dea.gov/sites/default/files/2020-03/DEA_GOV_DIR-008-20%20Fentanyl%20Flow%20in%20the%20United%20States_0.pdf
31. Executive Office of the President, Office of National Drug Control Policy. Countering illicit fentanyl trafficking. Foreign Relations Committee, United States Senate Statement of Dr. Rahul Gupta Director Office of National Drug Control Policy. February 15, 2023. Accessed May 14, 2023. https://www.foreign.senate.gov/imo/media/doc/f4597c23-de04-fa71-e612-bcbc49b6826c/021523_Gupta_Testimony.pdf
32. Felbab-Brown V. China and synthetic drugs control: fentanyl, methamphetamines, and precursors. Brookings. March 2022. Accessed 17 May 2023. https://www.brookings.edu/research/china-and-synthetic-drugs-control-fentanyl-methamphetamines-and-precursors
33. Dudley S, Bonello D, Lopez-Aranda J, Moreno M, Clavel T, Kjelstad B, et al. Mexico's role in the deadly rise of fentanyl. Wilson Center and InSight Crime. February 2019. Accessed May 19, 2023. https://www.wilsoncenter.org/sites/default/files/media/documents/publication/fentanyl_insight_crime_final_19-02-11.pdf
34. ICE. Statement of Steven Hagen, Assistant Director, Homeland Security. A field hearing on "Deadly distribution: How fentanyl crosses borders and claims lives." International Narcotics Control. October 27, 2022. Accessed May 18, 2023. https://www.ice.gov/doclib/news/library/speeches/221027cagen.pdf
35. Chapparo LA. $200 million load of fentanyl was just seized in El Chapo's hometown. Vice. 2022 October 27. Accessed May 20, 2023. https://www.vice.com/en/article/xgyxgz/mexico-sinaloa-fentanylmexico-sinaloa-fentanyl
36. Greenwood L, Fashola K. Illicit fentanyl from China: An evolving global operation. US. China Economic and Security Review Commission: Issue Brief. August 24, 2021. Accessed May 16, 2023. https://www.uscc.gov/sites/default/files/2021-08/Illicit_Fentanyl_from_China-An_Evolving_Global_Operation.pdf
37. Wang C, Lassi N. Combating illicit fentanyl: will increased Chinese regulation generate a public health crisis in India? Front Public Health. 2022;10:969395. https://doi.org/10.3389/fpubh.2022.969395
38. Van Hout MC, Bingham T. Responsible vendors, intelligent consumers: silk road, the online revolution in drug trading. Int J Drug Policy. 2014;25(2):183–9. https://doi.org/10.1016/j.drugpo.2013.10.009
39. Van Hout MC, Bingham T. 'Surfing the silk road': a study of users' experiences. Int J Drug Policy. 2013;24:524–9. https://doi.org/10.1016/j.drugpo.2013.08.011
40. Rhumorbarbe D, Staehli L, Broséus J, Rossy Q, Esseiva P. Buying drugs on a darknet market: a better deal? Studying the online illicit drug market through the analysis of digital, physical and chemical data. Forensic Sci Int. 2016;267:173–82. https://doi.org/10.1016/j.forsciint.2016.08.032
41. Broadhurst R, Lord D, Maxim D, Woodford-Smith H, Johnson C, Chung HW, et al. Malware trends on 'darknet' crypto-markets: research review. Canberra, Australia: Australian National University, Cybercrime Observatory; 2018. https://doi.org/10.13140/RG.2.2.36312.60168
42. Tzanetakis M. Comparing cryptomarkets for drugs. A characterisation of sellers and buyers over time. Int J Drug Policy. 2018;56:176–86. https://doi.org/10.1016/j.drugpo.2018.01.022

43. Howell CJ, Fisher T, Muniz CN, Maimon D, Rotzinger Y. A depiction and classification of the stolen data market ecosystem and comprising darknet markets: a multidisciplinary approach. J Contemp Crim Justice. 2023;39(2):298–317. https://doi.org/10.1177/10439862231158005
44. Broadhurst R, Ball M, Trivedi H. Fentanyl availability on darknet markets. Trends and issues in crime and criminal justice, No. 590. Australian Institute of Criminology: Canberra, Australia; 2020. https://doi.org/10.52922/ti04244
45. Van Hout MC, Bingham T. "Silk road", the virtual drug marketplace: a single case study of user experiences. Int J Drug Policy. 2013;24:385–91. https://doi.org/10.1016/j.drugpo.2013.01.005
46. Aldridge J, Décary-Hétu D. Not an "Ebay for drugs": the cryptomarket "silk road" as a paradigm shifting criminal innovation. Soc Sci Res Netw. 2014;1–29. https://doi.org/10.2139/ssrn.2436643
47. Duxbury SW, Haynie DL. The network structure of opioid distribution on a darknet cryptomarket. J Quant Criminol. 2018;34:921–41. https://doi.org/10.1007/s10940-017-9359-4
48. Aldridge J, Décary-Hétu D. Hidden wholesale: the drug diffusing capacity of online drug cryptomarkets. Int J Drug Policy. 2016;35:7–15. https://doi.org/10.1016/j.drugpo.2016.04.020
49. Bancroft A, Reid SP. Concepts of illicit drug quality among darknet market users: purity, embodied experience, craft and chemical knowledge. Int J Drug Policy. 2016;35:42–9. https://doi.org/10.1016/j.drugpo.2015.11.008
50. Barratt MJ, Ferris JA, Lenton S. Hidden populations, online purposive sampling, and external validity. Field Methods. 2014;27(1):3–21. https://doi.org/10.1177/1525822x14526838
51. Kamphausen G, Werse B. Digital figurations in the online trade of illicit drugs: a qualitative content analysis of darknet forums. Int J Drug Policy. 2019;73:281–7. https://doi.org/10.1016/j.drugpo.2019.04.011
52. Barratt MJ, Ferris JA, Winstock AR. Use of silk road, the online drug marketplace, in the United Kingdom, Australia and The United States. Addiction. 2014;109(5):774–83. https://doi.org/10.1111/add.12470
53. Barratt MJ, Maddox A. Active engagement with stigmatised communities through digital ethnography. Qual Res. 2016;16(6):701–19. https://doi.org/10.1177/1468794116648766
54. Ferguson R-H. Offline 'stranger' and R online lurker: methods for an ethnography of illicit transactions on the darknet. Qual Res. 2017;17(6):683–98. https://doi.org/10.1177/1468794117718894
55. Szgeti Á, Frank R, Kiss T. Trust factors in the social figuration of online drug trafficking: a qualitative content analysis on a darknet market. J Contemp Crim Justice. 2023;39(2):167–84. https://doi.org/10.1177/10439862231159996
56. Everton SF. Disrupting dark networks. Vol 34. Cambridge, UK: Cambridge University Press; 2012. p. 8.
57. Pete I, Hughes J, Chua YT, Bada M. A social network analysis and comparison of six dark web forums. Proceedings of the 2020 IEEE European symposium on security and privacy workshops (EuroS&PW); 2020 sept 7–11; held virtually. Washington, DC: IEEE Computer Society; 2020. p. 484–93. https://doi.org/10.1109/EuroSPW51379.2020.00071
58. Malm AE, Bichler G. Why networks? In: Bichler G, Malm AE, editors. Disrupting criminal networks: network analysis in crime prevention. Boulder, CO/London, UK: FirstForumPress; 2015. p. 1–8.
59. Ouellet M, Maimon D, Howell CJ, Wu Y. The network of online stolen data markets: how vendor flows connect digital marketplaces. Brit J Criminol. 2022;62(6):1518–36. https://doi.org/10.1093/bjc/azab116
60. Meland PH, Bayoumy YFF, Sindre G. The ransomware-as-a-service economy within the darknet. Comput Secur. 2020;92:101762. https://doi.org/10.1016/j.cose.2020.101762
61. Broadhurst R, Foyce J, Jiang C, Ball M. Illicit firearms and other weapons on darknet markets. Trends & Issues in crime and criminal justice, No. 622. Australian Institute of Criminology: Canberra, Australia; 2021. https://doi.org/10.52922/ti78009
62. Harrison JR, Roberts DL, Hernandez-Castro J. Assessing the extent and nature of wildlife trade on the dark web. Conserv Biol. 2016;30:900–4.
63. Wright J. Darknet usage in the illegal wildlife trade. Oxford, UK: University of Oxford Press; 2019.
64. Europol. Intellectual property crime on the darknet. 2017. Accessed May 20, 2023. https://www.europol.europa.eu/sites/default/files/documents/darknet.pdf
65. Ablon L, Libicki MC, Golay AA. Markets for cybercrime tools and stolen data: Hackers' bazaar. Santa Monica, CA: RAND Corporation; 2014.
66. Steel CM. Stolen identity valuation and market evolution on the dark web. Int J Cyber Criminol. 2019;13(1):70–83. https://doi.org/10.5281/zenodo.3539500
67. Holt TJ, Lee JR, O'Dell E. Assessing the practices of online counterfeit currency vendors. Crime Delinq. 2022. https://doi.org/10.1177/00111287221134047
68. Lamy DR, Barratt MJ, Lokala U, Sheth A, Carlson RG. Listed for sale: analyzing data on fentanyl, fentanyl analogs and other novel synthetic opioids on one cryptomarket. Drug Alcohol Depend. 2020;213:108115. https://doi.org/10.1016/j.drugalcdep.2020.108115
69. Maras M-H, Arsovska J, Wandt A, Logie K. Keeping pace with the evolution of illicit darknet markets: identifying trust signals and developing a vendor trustworthiness index. J Contemp Crim Justice. 2023;39(2):276–97. https://doi.org/10.1177/10439862231159530
70. Broadhurst R, Ball M, Jiang C, Wang J, Trivedi H. Impact of darknet market seizures on opioid availability. Research report, No. 18. Australian Institute of Criminology: Canberra, Australia; 2021. https://doi.org/10.52922/rr04886
71. Newton-Small J. The Silk Road is back: The Dread Pirate Roberts sails the illicit online drug trade again. 2014. Accessed July 6, 2023. https://time.com/82552/the-silk-road-is-back-the-dread-pirate-roberts-sails-the-illicit-online-drug-trade-again/
72. Lokala U, Lamy FR, Daniulaityte R, Sheth A, Nahhas RW, Roden JI, et al. Global trends, local harms: availability of fentanyl-type drugs on the dark web and accidental overdoses in Ohio. Comput Math Organ Theory. 2019;25(1):48–59. https://doi.org/10.1007/s10588-018-09283-0
73. Negri A, Townshend H, McSweeney T, Angelopoulou O, Banayoti H, Prilutskaya M, et al. Carfentanil on the darknet: potential scam or alarming public health threat? Int J Drug Policy. 2021;91:103118. https://doi.org/10.1016/j.drugpo.2021.103118
74. European Monitoring Center for Drugs and Drug Addiction (EMCDDA) and Europol. Darknet markets ecosystem. 2018. Accessed May 20, 2023. https://www.emcdda.europa.eu/darknet_en
75. Tzanetakis M, Kamphausen G, Werse B, von Laufenberg R. The transparency paradox. Building trust, resolving disputes and optimising logistics on conventional and online drugs markets. Int J Drug Policy. 2016;35:58–68. https://doi.org/10.1016/j.drugpo.2015.12.010
76. Espinosa R. Scamming and the reputation of drug dealers on darknet markets. Int J Ind Organ. 2019;67:102523. https://doi.org/10.1016/j.ijindorg.2019.102523
77. Van Buskirk J, Bruno R, Dobbins T, Breen C, Burns L, Naicker S, et al. The recovery of online drug markets following law enforcement and other disruptions. Drug Alcohol Depend. 2017;173:159–62. https://doi.org/10.1016/j.drugalcdep.2017.01.004
78. Tidy J, Benjamin A. Largest darknet stolen credit card site closes. BBC News 2022. Accessed May 15, 2023. https://www.bbc.com/news/technology-59983950
79. Greenberg A. AlphaBay is taking over the dark web—again. Wired 2022. Accessed May 21, 2023. https://www.wired.com/story/alphabay-dark-web-market-ranking/
80. Lorenzo-Dus N, Di Cristofaro M. 'I know this whole market is based on the trust you put in me and I don't take that lightly':

trust, community and discourse in crypto-drug markets. Discourse Commun. 2018;12(6):608–26. https://doi.org/10.1177/1750481318771429
81. Maras M-H, Arsovska J, Wandt AS, Knieps M, Logie K. The SECI model and darknet markets: knowledge creation and sharing in criminal organizations and communities of practice. Eur J Criminol. 2022. https://doi.org/10.1177/14773708221115167
82. Bazli B, Wilson M, Hurst W. The dark side of I2P, a forensic analysis case study. Syst Sci Control Eng. 2017;5(1):278–86. https://doi.org/10.1080/21642583.2017.1331770
83. Magan-Carrion R, Abellan-Galera A, Macia-Fernandez G, Garcia-Teodoro P. Unveiling the I2P web structure: a connectivity analysis. Comput Networks. 2021;194:1–13. https://doi.org/10.48550/arXiv.2101.03212
84. United States v. Alexandre Cazes. 2017. Accessed July 6, 2023. https://www.justice.gov/opa/press-release/file/982826/download
85. FBI. Darknet takedown: Authorities shutter online criminal market Alphabay. 2017. Accessed May 21, 2023https://www.fbi.gov/news/stories/alphabay-takedown
86. Gibbs S, Beckett L. Dark web marketplaces AlphaBay and Hansa shut down. The Guardian. 2017. Accessed May 19, 2023. https://www.theguardian.com/technology/2017/jul/20/dark-web-marketplaces-alphabay-hansa-shut-down
87. Europol. Massive blow to criminal dark web activities after globally coordinated operation. July 20, 2017. Accessed May 20, 2023. https://www.europol.europa.eu/media-press/newsroom/news/massive-blow-to-criminal-dark-web-activities-after-globally-coordinated-operation
88. Branwen G, Christin N, Décary-Hétu D, Andersen RM, StExo, Presidente E, et al. Dark net market archives. 2015. Accessed May 17, 2023. https://www.gwern.net/DNM-archive
89. DEA Intelligence Report. Slang terms and code words: A reference for law enforcement personnel. DEA-HOU-DIR-022-18 2018. Accessed May 20, 2023. https://www.dea.gov/sites/default/files/2018-07/DIR-022-18.pdf
90. Wasserman S, Faust K. Social network analysis: methods and applications. Cambridge, UK: Cambridge University Press; 2009. p. 3–27.
91. United States v. Christopher Hampton, Case 2:22-cr-00549 (C.D. California, 2022).
92. US Drug Enforcement Administration. DEA St. Louis Division breaks fentanyl seizure record. 2022. Accessed May 18, 2023. https://www.dea.gov/press-releases/2022/11/07/dea-st-louis-division-breaks-fentanyl-seizure-record
93. Ontario Provincial Police. Opioids and overdoses: impacts and strategies. Ontario, Canada: Organized Crime Enforcement Bureau; 2019. Accessed July 5, 2023. https://www.publications.gov.on.ca/CL29475
94. Jadoon AK, Iqbal W, Amjad MF, Afzal H, Bangash YA. Forensic analysis of tor browser: a case study for privacy and anonymity on the web. Forensic Sci Int. 2019;299:59–73. https://doi.org/10.1016/j.forsciint.2019.03.030
95. Leng T, Yu A. A framework of darknet forensics. Proceedings of the 3rd international conference on advanced information science and system; 2021 Nov 26–28; Sanya, China. New York, NY: Association for Computing Machinery; 2022. p. 1–6. https://doi.org/10.1145/3503047.3503082
96. The Chainalysis. Crypto crime report. 2021. https://go.chainalysis.com/2021-Crypto-Crime-Report.html. Accessed May 14, 2023
97. Mounteney J, Cunningham A, Groshkova T, Sedefov R, Griffiths P. Looking to the future-more concern than optimism that cryptomarkets will reduce drug-related harms. Addiction. 2018;113(5):799–800. https://doi.org/10.1111/add.14056
98. Hosseini Shirvani M, Akbarifar A. A comparative study on anonymizing networks: ToR, I2P, and riffle networks comparison. J Electr Comput Eng. 2022;10(2):259–72. https://doi.org/10.22061/jecei.2021.8027.466

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Maras M-H, Logie K, Arsovska J, Wandt AS, Barthuly B. Decoding hidden darknet networks: What we learned about the illicit fentanyl trade on AlphaBay. J Forensic Sci. 2023;00:1–19. https://doi.org/10.1111/1556-4029.15341