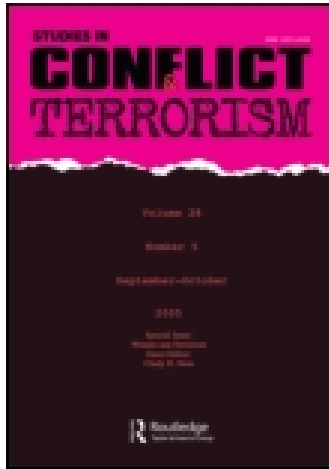


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Estimating the Duration of *Jihadi* Terror Plots in the United States

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The number of ongoing terror plots increases with the duration of time from plot initiation until plot execution or interdiction (whichever comes first), yet no estimate of the probability distribution governing terror plot duration has appeared in the open literature. To remedy this gap, jihadi terror plots in the United States were identified from terrorism-related indictments that occurred between 11 September 2001 and 30 June 2011 in addition to successful attacks. From a review of indictments, affidavits, and other publicly available information, it was possible to identify lower and upper bounds for the initiation date of the plot in question as well as the ending date corresponding to either the arrest of the suspect(s) eventually convicted or an attempted/actual act of terror. These observations enable estimation of the duration distribution of jihadi terror plots in the United States accounting for the censoring and truncation effects inherent with these data (technical details appear in the Appendix). The estimated mean plot duration equals 270 days (standard error of mean 40 days), while 95 percent of all plots are estimated to fall between 33 and 750 days. These estimates suggest that on average, approximately three ongoing terror plots have been active in the United States at any point since 11 September 2001.

The starting point for much empirical terrorism research has been data describing terror attacks over time.¹ A terror attack is the last step in a process that begins when an individual or group decides to commit an act of terrorism and begins plotting towards that end, and more recently researchers have focused their attention on terror plots as objects of analysis to understand their differential anatomy,² examine why some plots succeed and others fail,³ or to ascertain counterterrorism law enforcement practices and judicial outcomes.⁴ Lacking in the open literature is a systematic attempt to characterize the duration of terror plots, that is, the time that passes from an individual's or group's initial decision to pursue an act of terror until the execution or interdiction of the resulting terror plot, whichever comes

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first. This knowledge gap is somewhat surprising, for other things being equal, the number of ongoing terror plots increases with plot duration. Indeed, knowledge of the probability distribution of terror plot duration enables estimation of the prevalence of terror plots-in-progress.⁵ Building upon a review of publicly available documents describing *jihadi* terror plots in the United States, the present report develops an estimate for the duration distribution of *jihadi* terror plots, and illustrates the use of this distribution to estimate the expected number of ongoing terror plots over time.

Data

The Terrorist Trial Report Card (TTRC) project at the Center on Law and Security at the New York University School of Law maintains a database documenting all federal terrorism prosecutions since 11 September 2001.⁶ These data contain information regarding 1,054 prosecutions associated with 846 distinct defendants organized by date of indictment from 11 September 2001 through 30 June 2011. Fifty-five percent of these were motivated by *jihadi* ideas, where TTRC's definition of *Jihadi* cases "... includes defendants who were formally or informally associated with an Islamist terror group—whether one with a global jihadist ideology (i.e. Al Qaeda) or a local Islamist movement (i.e. Hamas). It also includes defendants unaffiliated with a terror group who aspired to such affiliation or who subscribed to a global jihadist ideology."⁷ However, as the TTRC reports make clear, the overwhelming majority of those prosecuted did not link to specific terror plots targeting the United States, with many accused of providing material support to terrorists or foreign terrorist organizations. Material support "... includes any property or service, exempting medicine or religious materials. Services can include training, expert advice, personnel (including oneself), transportation, safe houses, communications, and more."⁸ Review of the *jihadi* cases listed in the TTRC data surfaced 26 that *were* linked to plans to attack Americans. In addition to the TTRC data, a listing of purported terror plots against the United States from 1999 to 2009 appears in a recent study by researchers at the Institute for Homeland Security Solutions.⁹ Of the 86 plots identified in that study, 40 are identified as planned or inspired by Al Qaeda or an affiliated movement and thus qualify as *jihadi* plots. However, after again excluding cases with insufficiently specific plans to attack Americans, an additional nine cases were identified, raising the total number of plots to 35.

Each of these 35 plots has an associated date on which either a terror attack was attempted/successfully carried out (7 cases), or the suspect(s) were arrested (28 cases). However, to determine the duration of a terror plot requires knowing when a plot begins. Rather than attempt to ascertain precise starting points, relevant court records such as indictments, criminal complaints, and other supporting legal documents in addition to media reports and other public sources were reviewed with the goal of identifying early and late start dates for each plot. The idea is to specify a time interval during which one can be reasonably certain that the plot in question began, and apply appropriate statistical methods that account for the uncertainty in the actual starting date that stems from only being able to specify such upper and lower bounds.

To illustrate the assignment of early and late starting dates, consider the California prison conspiracy where Kevin James, Levar Washington, and others were accused of plotting to attack military personnel at Los Angeles area recruitment centers and military bases, target the Los Angeles Israeli Consulate and El Al airlines office, and attack Los Angeles area synagogues. The indictment in this case states:¹⁰ "In or about December 2004, defendant JAMES instructed defendant WASHINGTON to (1) recruit five individuals without felony convictions and train them in covert operations; (2) acquire two firearms with silencers; and (3) appoint an individual from the group he recruited to find contacts

for explosives or learn to make bombs that could be activated from a distance"; indicating an early start date of 1 December 2004. The indictment continues to state that "Beginning on or about May 19, 2005, and continuing through on or about June 7, 2005, defendant PATTERSON used a computer to conduct internet research on the Israeli Consulate in Los Angeles," which suggests 19 May 2005 as a late start date.

As a second example, consider the plot to attack the Fort Dix military base. From the criminal complaint filed by FBI Special Agent John J. Ryan,¹¹ "On or about January 3, 2006, MOHAMAD SHNEWER, DRITAN DUKA, ELTVIR DUKA, SHAIN DUKA, and SERDAR TATAR conducted firearms training in Gouldsboro, Pennsylvania," while later in the complaint Ryan states¹² "On or about August 11, 2006, CW-1 (author note: CW = cooperating witness) and MOHAMAD SHNEWER traveled to the Fort Dix military base to conduct surveillance When CW-1 asked what made SHNEWER think of Fort Dix as a target, SHNEWER replied, 'My intent is to hit a heavy concentration of soldiers' As SHNEWER and CW-1 drove into a specific area at Fort Dix, SHNEWER said, ' . . . this is exactly what we are looking for. You hit 4, 5, or 6 humvees and light the whole place [up] and retreat completely without any losses.'" On this basis, early and late start dates were assigned to 3 January and 11 August, respectively.

This strategy produced sufficient information to specify early and late start dates for 30 of the 35 plots in question. For each of these remaining 30 plots, Table 1 reports the names of key persons convicted, the early and late start dates, the date of arrest or attack, and notes indicating sources consulted to establish the three dates listed.

Estimating the Duration Distribution

Define τ_e , τ_l , and τ_c as the early start, late start, and completion (arrest/attack) dates for a particular plot. Also, define D as the random variable denoting plot duration. Assuming that the true starting time of a plot is equally likely to fall anywhere between τ_e and τ_l , the likelihood of observing a plot that ends at τ_c is given by (Appendix)

$$\frac{\Pr\{\tau_c - \tau_l < D \leq \tau_c - \tau_e\}}{\tau_l - \tau_e} = \frac{S(\tau_c - \tau_l) - S(\tau_c - \tau_e)}{\tau_l - \tau_e} \quad (1)$$

where $S(x) = \Pr\{D > x\}$ is the survivor distribution of the plot duration D . Since only plots with completion dates between 11 September 2001 (denoted by τ_s) and 30 June 2011 (denoted by τ_f) are included in the sample, the likelihood function above must be divided by the *a priori* probability that the completion date of the plot in question falls between τ_s and τ_f to account for truncation. This latter probability can be written as (Appendix)

$$\frac{\int_{\tau_e}^{\tau_l} \{S(\tau_s - x) - S(\tau_f - x)\} dx}{\tau_l - \tau_e}. \quad (2)$$

Letting the subscript i indicate the identity of each plot, $i = 1, 2, \dots, 30$, the overall conditional likelihood \mathcal{L} is then given by

$$\mathcal{L} = \prod_{i=1}^{30} \frac{S(\tau_{c_i} - \tau_{l_i}) - S(\tau_{c_i} - \tau_{e_i})}{\int_{\tau_{e_i}}^{\tau_{l_i}} \{S(\tau_s - x) - S(\tau_f - x)\} dx}. \quad (3)$$

Maximum likelihood estimates of the parameters of any presumed duration distribution can then be obtained by maximizing \mathcal{L} (or equivalently its logarithm) as a function of the parameters in question, while an approximate nonparametric estimate for the duration distribution can also be obtained (all statistical estimation details in Appendix).

Table 1
Terror plot early start, late start and completion times

Plot	Key convicts	Early start (τ_e)	Late start (τ_l)	End date (τ_c)	Source
Shoe Bomb	Richard Reid	7/1/2000	7/7/2001	12/23/2001	13
Dirty Bomb	Jose Padilla	7/24/2000	7/1/2001	5/8/2002	14
Brooklyn Bridge	Iyman Faris	1/1/2002	3/1/2002	3/19/2003	15
President Bush	Ahmed Omar Abu Ali	9/1/2002	9/30/2002	6/9/2003	16
Columbus OH shopping mall	Nuradin Abdi	1/1/2000	8/6/2002	11/28/2003	17
Shoulder fired missiles	Yasin Aref and Mohammed Mosharref Hossain	7/1/2003	11/20/2003	8/4/2004	18
Chicago courthouse	Gate William Nettles	7/1/2003	11/25/2003	8/5/2004	19
Herald Square subway	Shawward Martin Siraj and James Elshafay	6/1/2004	6/30/2004	8/27/2004	20
Sell bomb to Al Qaeda	Ronald Allen Grecula	7/1/2002	12/31/2002	5/20/2005	21
California prison conspiracy	Kevin James and Levar Washington	12/1/2004	5/19/2005	8/31/2005	22
Chicago Sears Tower	Narseal Batiste et al ("Liberty City Seven")	11/1/2005	12/16/2005	6/22/2006	23
Liquid explosives on airlines	Abdulla Ahmed Ali et al ("Operation Overt")	12/15/2005	5/15/2006	8/9/2006	24
Rockford IL shopping center	Derrick Shareef	9/1/2006	11/29/2006	12/6/2006	25
Fort Dix NJ	Mohamed Ibrahim Shnewer et al.	1/3/2006	8/11/2006	5/7/2007	26
Fuel tanks at JFK airport	Russell Defreitas et al.	1/1/2006	8/1/2006	6/2/2007	27
South Florida pipe bombs	Ahmed Abdellatif Sherif Mohamed	1/1/2007	7/11/2007	8/4/2007	28
Bronx NY synagogue/Stinger missiles	James Cromitie et al	6/1/2008	4/10/2009	5/19/2009	29
Little Rock shootings	Abdulahakim Muhajahid Muhammad	11/14/2008	1/29/2009	6/1/2009	30
New York City subway	Najibullah Zazi	8/28/2008	12/1/2008	9/19/2009	31
Springfield IL courthouse	Michael C. Finton	11/11/2008	1/2/2009	9/23/2009	32
Fountain Place in Dallas TX	Hosam Maher Husein Smadi	1/1/2009	6/24/2009	9/24/2009	33
Fort Hood shootings	Nidal Hassan	12/1/2008	7/31/2009	11/5/2009	34
"Underwear bomb"	Umar Farouk Abdulmutallab	8/1/2009	10/15/2009	12/25/2009	35
Times Square car bomb	Faisal Shahzad	12/1/2009	2/25/2010	5/1/2010	36
Wrigley Field backpack bomb	Sami Samir Hasoun	5/29/2010	6/4/2010	9/19/2010	37
DC Metrorail	Farooque Ahmed	1/1/2010	5/15/2010	10/26/2010	38
Portland OR Christmas tree lighting	Mohamed Osman Mohamud	8/1/2009	8/19/2010	11/26/2010	39
Maryland military recruitment center	Antonio Benjamin Martinez	9/29/2010	10/22/2010	12/8/2010	40
Colorado dams and President Bush	Khalid Ali Aldawsari	3/11/2010	10/19/2010	2/23/2011	41
New York City synagogue	Ahmed Ferhani and Mohamed Mamdough	10/15/2010	4/12/2011	5/11/2011	42

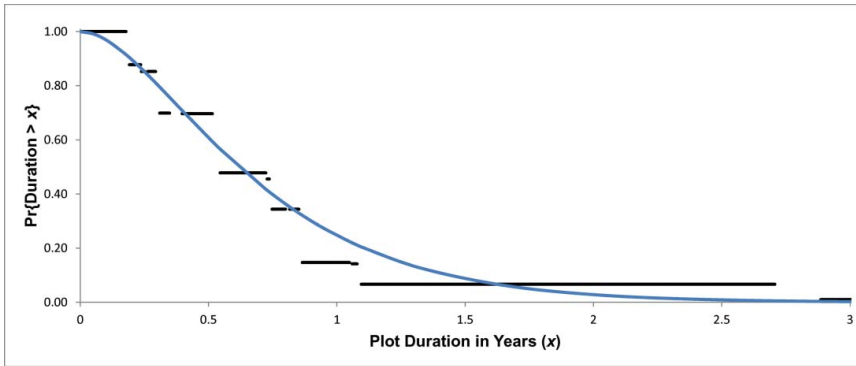


Figure 1. Error plot duration distribution. (Color figure available online).

Figure 1 reports the estimated nonparametric duration distribution (steps) along with an Erlang-2 distribution (smooth curve) representing the sum of two independent exponential random variables (justification in Appendix). Both distributions produce similar estimates for the mean plot duration: the nonparametric estimate equals 268 days (standard error of the mean 43 days), while the Erlang-2 estimate equals 270 days (standard error of the mean 41 days). The Erlang-2 suggests that 95 percent of all terror plots last 33 to 750 days.

Estimating the Number of Active Plots

Knowledge of the mean terror plot duration enables estimation of the number of terror plots in process, providing that only plots that will eventually be executed or interdicted are considered (plots that fizzle out on their own are not included). If α is the terror plot initiation rate measured in plots per unit time, $E(N)$ is the expected number of ongoing terror plots, and $E(D)$ is the mean terror plot duration, then

$$E(N) = \alpha E(D) \quad (4)$$

via Little's Law from queueing theory.⁴³ Equivalently, Equation (4) can be viewed as an instance of the well known prevalence = incidence \times duration law from epidemiology.⁴⁴ Sufficient justification for application of Equation (4) follows from the fact that at least in the United States, the incidence of actual and attempted terror attacks over time has been consistent with a Poisson process as documented by Gleason for actual terror incidents between 1968–74,⁴⁵ and implied by Strom et al.'s data for successful and failed attacks.⁴⁶ A further argument suggesting that Poisson plot initiation is a reasonable assumption in the United States follows from noting that the majority of U.S. *jihadi* terror plots have been self-initiated by disaffected individuals scheming independently of each other over time and location, as opposed to having been strategically coordinated (and strategically timed) by Al Qaeda from afar.⁴⁷

Consider now the application of Equation (4) to the observable plots in Table 1 (i.e., those plots with observable early and late start times). The plot initiation rate α equals the plot completion rate per unit time for all plots that are either executed or interdicted must come to an end. The 30 plots in Table 1 occurred over the 9.8 years from 11 September 2001 to 30 June 2011, thus the estimated observable plot initiation rate equals $30/9.8 = 3.06$ plots per year. The mean plot duration was estimated previously to equal approximately

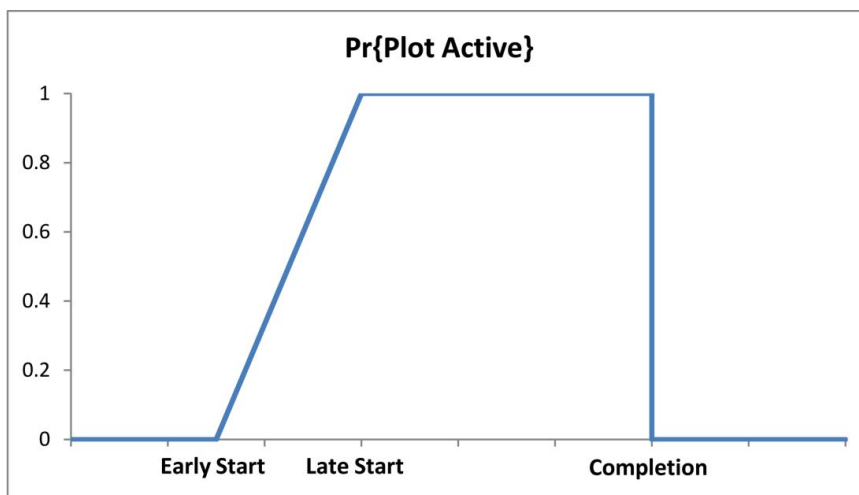


Figure 2. Probability that a plot is active. (Color figure available online).

270 days or about 0.74 years, thus application of Equation (4) suggests $3.06 \times 0.74 = 2.26$ observable plots in progress on average at any point in time within the study period (95 percent confidence interval 1.42–3.6, Appendix). To check the reasonability of this calculation, for the plots in Table 1 it is possible to estimate the number of plots in progress over time directly without reference to the estimated duration distribution. As illustrated in Figure 2, note that at any time t , the probability $p(t)$ that a particular plot is active is, by the early/late start time assumption, given by

$$p(t) = \begin{cases} 0 & t \leq \tau_e, t > \tau_c \\ \frac{t - \tau_e}{\tau_\ell - \tau_e} & \tau_e < t \leq \tau_\ell \\ 1 & \tau_\ell < t \leq \tau_c \end{cases} . \quad (5)$$

Letting $p_i(t)$ equal the probability that the i^{th} plot in the sample is active at time t for $i = 1, 2, \dots, 30$ and $\tau_s < t \leq \tau_f$, the estimated mean number of observable active plots at time t is given by

$$E[N(t)] = \sum_{i=1}^{30} p_i(t). \quad (6)$$

Applying Equation (6) to the data in Table 1 yields the estimated number of observable plots in progress shown in Figure 3. Also shown is the expected number of active plots one would expect to observe after accounting for truncation. For the first 8 years of these data, the estimated number of active plots fluctuates in random fashion about the estimated 2.26 mean number of active plots from Equation (4). Over the remaining two years, the number of active plots from Table 1 must decline to zero as the end of the study period is reached. The expected number of observable plots at time t adjusted for this truncation effect is given by $\alpha E(D) \Pr\{D^* \leq \tau_f - t\}$, where D^* is the remaining duration of a randomly selected plot in progress (Appendix). The correspondence in Figure 3 between $E[N(t)]$ (jagged line) and the expected number of observable plots based on the duration distribution (smooth line) supports the use of Equation (4) to estimate the mean number of ongoing terror

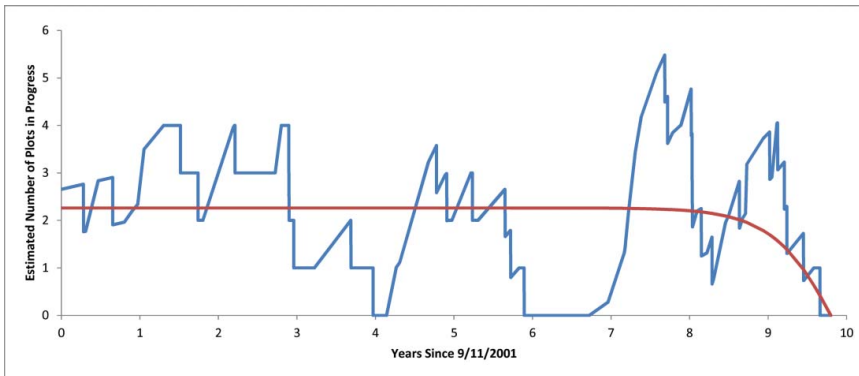


Figure 3. Estimated number of terror plots in progress. (Color figure available online).

plots in progress. Accounting for the additional five plots identified without starting time information requires inflating the expected number of plots in progress at any point in time by 35/30; this raises the estimated number of active *jihadi* plots in the United States to 2.64 at any point since 11 September 2001.

Conclusion

Estimating the number of terror plots in progress is important for basic decision making in counterterrorism intelligence: when should a terror alert be issued,⁴⁸ how many counterterrorism undercover agents are needed, and how should their activity be managed?⁴⁹ While the news media has on occasion released estimates of the number of terror suspects based on surveillance by intelligence agencies,⁵⁰ such estimates depend critically on an agency's surveillance effort and are also subject to high false positive rates.⁵¹ The present study has taken an entirely different approach to estimating the number of ongoing terror plots. By focusing on the duration of time from plot initiation to the interdiction or occurrence of a terror attack, it is possible to employ simple and defensible models to estimate the prevalence of terror plots. While publicly available data were employed in the present study, the methods described for estimating the duration distribution could be applied to more refined data of the form only intelligence agencies are likely to possess.

Notes

1. Commonly used terrorism databases include ITERATE (available at <http://vinyardsoftware.com/>), the Global Terrorism Database (available at <http://www.start.umd.edu/gtd/>), and the Worldwide Incidents Tracking System (available at <https://wits.nctc.gov/FederalDiscoverWITS/index.do?N=0>). For further discussion of empirical analysis of terrorism databases see Walter Enders and Todd Sandler, *The Political Economy of Terrorism* (Cambridge: Cambridge University Press, 2011).

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Appendix: Estimating the Duration of *Jihadi* Terror Plots in the United States

Deriving the Likelihood Function

Let τ_e , τ_ℓ , and τ_c denote the early start, late start, and completion (arrest/attack) dates for a particular plot. Also, define D as the random variable denoting plot duration with probability density $f_D(x)$ and survivor distribution $S(x) = \Pr\{D > x\}$. Assuming that the true starting time of a plot is uniformly distributed between τ_e and τ_ℓ , the likelihood of observing a plot that ends at τ_c is found from

$$\begin{aligned} \frac{\int_{\tau_e}^{\tau_\ell} f_D(\tau_c - x) dx}{\tau_\ell - \tau_e} &= \frac{\Pr\{\tau_c - \tau_\ell < D \leq \tau_c - \tau_e\}}{\tau_\ell - \tau_e} \\ &= \frac{S(\tau_c - \tau_\ell) - S(\tau_c - \tau_e)}{\tau_\ell - \tau_e}. \end{aligned} \quad (\text{A1})$$

To determine the probability that the completion date of a plot in question falls between the starting date τ_s (11 September 2001) and finishing date τ_f (30 June 2011) of the study, note that any plot that begins at time x will be completed between τ_s and τ_f with probability $\Pr\{\tau_s - x < D \leq \tau_f - x\} = S(\tau_s - x) - S(\tau_f - x)$. Given that the plot starting date is uniformly distributed between τ_e and τ_ℓ , the probability that a plot finishes between τ_s and τ_f equals

$$\frac{\int_{\tau_e}^{\tau_\ell} \Pr\{\tau_s - x < D \leq \tau_f - x\} dx}{\tau_\ell - \tau_e} = \frac{\int_{\tau_e}^{\tau_\ell} \{S(\tau_s - x) - S(\tau_f - x)\} dx}{\tau_\ell - \tau_e}. \quad (\text{A2})$$

The conditional likelihood of observing a plot with a completion date of τ_c given that the plot started at a uniform time between τ_e and τ_ℓ and the plot was completed between τ_s and τ_f (that is, the plot is observable in the study) then equals the ratio of Equation (A1) to Equation (A2), and letting i indicate the identify of each plot, $i = 1, 2, \dots, 30$, it follows

that the overall conditional likelihood L equals

$$L = \prod_{i=1}^{30} \frac{S(\tau_{c_i} - \tau_{\ell_i}) - S(\tau_{c_i} - \tau_{e_i})}{\int_{\tau_{e_i}}^{\tau_{\ell_i}} \{S(\tau_s - x) - S(\tau_f - x)\} dx}. \quad (\text{A3})$$

Parametric Duration Distributions

Applied to the data in Table 1 of the main text, maximization of Equation (A3) (or equivalently and more practically its logarithm) as a function of unknown parameters produces maximum likelihood estimates (MLEs) for the parameters of the terror plot duration model in question, while the estimated covariance matrix for model parameters can be found in standard fashion via inversion of the associated Hessian matrix evaluated at the MLEs.¹ This section presents the results of fitting various models culminating with the choice of the Erlang-2 distribution.

The simplest duration distribution to consider is the *exponential* with mean $1/\mu$ and survivor distribution given by

$$S(x) = \begin{cases} 1 & x \leq 0 \\ e^{-\mu x} & x > 0 \end{cases}. \quad (\text{A4})$$

The resulting MLE is $\hat{\mu} = 0.00355 \text{ day}^{-1}$ implying an estimated mean plot duration of 282 days (standard error 64 days), with an associated log likelihood (logarithm of the maximized likelihood function) equal to -192 .

As a more general alternative, suppose that the planning of a terror attack requires at least two phases, the first of which is settling upon a particular target and mode of attack while the second involves arranging the logistics and executing the plan from the first phase (or the time until interdiction, whichever comes first). This suggests that the overall duration of an attack could be modeled as the sum of two random variables representing the two different phases of the plot. One such distribution follows from assuming that both phases follow exponential distributions with means $1/\mu_1$ and $1/\mu_2$ respectively (and overall mean duration is the sum of these). The survivor distribution can be derived by noting that the probability that the overall plot duration exceeds x time units equals the probability that the first phase of the plot alone exceeds x plus the probability that the first phase requires exactly $u \leq x$ time units *and* the second phase requires at least $x - u$ time units. The survivor distribution for this model is thus given by

$$S(x) = \begin{cases} 1 & x \leq 0 \\ e^{-\mu_1 x} + \int_0^x \mu_1 e^{-\mu_1 u} e^{-\mu_2(x-u)} du & \\ = e^{-\mu_1 x} + \frac{\mu_1}{\mu_1 - \mu_2} (e^{-\mu_2 x} - e^{-\mu_1 x}) & x > 0 \end{cases}. \quad (\text{A5})$$

Note that this includes the exponential distribution of Equation (A4) as the special case where $\mu_2 \rightarrow \infty$. The resulting MLEs for this model are $\hat{\mu}_1 = 0.01034 \text{ day}^{-1}$ and $\hat{\mu}_2 = 0.00574 \text{ day}^{-1}$ for an estimated mean plot duration of 271 days (standard error 44 days) and associated log likelihood equal to -188.3 . The difference between the phase and exponential log likelihoods equals 3.7; as twice the difference in the log likelihood follows a χ^2 distribution with 1 degree of freedom, the exponential distribution is rejected in comparison with the phase model (p -value = 0.006).

An even simpler two phase model follows from assuming that both plot phases require the same amount of time on average. This yields the Erlang-2 model, which can be derived by taking the limit of Equation (A5) as $\mu_2 \rightarrow \mu_1$, or alternatively by computing the probability of at most one event occurring in a Poisson process. Either approach yields the following survivor distribution:

$$S(x) = \begin{cases} 1 & x \leq 0 \\ (1 + \mu x)e^{-\mu x} & x > 0 \end{cases} \quad (\text{A6})$$

The mean of the Erlang-2 distribution equals $2/\mu$. The MLE for the Erlang-2 is $\hat{\mu} = 0.00741 \text{ day}^{-1}$ with a estimated mean plot duration of $2/\hat{\mu} = 270$ days (standard error 41 days), and associated log likelihood of -188.4 . Comparing the Erlang-2 and two-phase models, the difference in log likelihoods only equals 0.1 which is not statistically significant (p -value = 0.65), thus we cannot reject the Erlang-2 model. This is the duration distribution plotted as the smooth curve in Figure 1 of the main text. Under this distribution, 95% of all terror plot durations fall between 33 and 750 days.

Approximate Nonparametric Duration Distribution

To free the analysis from parametric assumptions, one can also consider maximizing Equation (A3) as a function of the survivor distribution $S(x)$ directly, but the integral in the denominator complicates matters. To simplify the nonparametric estimation problem, the following midpoint approximation was applied:

$$\int_{\tau_e}^{\tau_\ell} S(x)dx \approx (\tau_\ell - \tau_e)S\left(\frac{\tau_e + \tau_\ell}{2}\right). \quad (\text{A7})$$

Application to Equation (A3) yields the following approximate likelihood function:

$$\mathcal{L} = \prod_{i=1}^{30} \frac{S(\tau_{c_i} - \tau_{\ell_i}) - S(\tau_{c_i} - \tau_{e_i})}{(\tau_{\ell_i} - \tau_{e_i}) \left\{ S\left(\tau_s - \frac{\tau_{e_i} + \tau_{\ell_i}}{2}\right) - S\left(\tau_f - \frac{\tau_{e_i} + \tau_{\ell_i}}{2}\right) \right\}}. \quad (\text{A8})$$

Equation (A8) is exactly of the form studied by Turnbull² for interval censored data as modified by Frydman³ to account for truncation. Applying Frydman's algorithm yields the nonparametric survivor distribution shown in Figure 1 (horizontal steps). The estimated mean duration equals 268 days (standard error 43 days), nearly identical to the results of the Erlang-2 model. The log likelihood associated with the nonparametric distribution equals -181.7 , which is not meaningfully larger than the Erlang-2 log likelihood considering that, as is clear from Figure 1, the nonparametric model contains 13 probability mass point parameters (compared to the single Erlang-2 parameter μ).

Confidence Interval for the Mean Number of Plots in Progress

The modeled mean number of plots in progress is given by $E(N) = \alpha E(D)$, or to simplify notation, $n = \alpha d$. The point estimate $\hat{n} = \hat{\alpha} \hat{d}$. The estimated initiation rate for observable plots in the data equals the completion rate of the same, which is simply the number of observed plots completed within the study period (30) divided by $\tau_f - \tau_s$, the length of time from 11 September 2001 to 30 June 2011. Thus, $\hat{\alpha} = 30/9.8 = 3.06$ plots/year. The mean plot duration was estimated above at $\hat{d} = 270$ days or 0.74 years (Erlang-2

model), implying that $\hat{n} = 3.06 \times 0.74 = 2.26$. A confidence interval for n that ensures the estimated mean number of plots remains non-negative can be achieved by taking the logarithm of \hat{n} and noting that the plot duration is independent of the plot initiation rate. Application of the delta method⁴ then yields

$$\begin{aligned}\widehat{\text{Var}}(\log \hat{n}) &\approx \frac{\widehat{\text{Var}}(\hat{\alpha})}{\hat{\alpha}^2} + \frac{\widehat{\text{Var}}(\hat{d})}{\hat{d}^2} \\ &= \frac{30/9.8^2}{(30/9.8)^2} + \frac{41^2}{270^2} = 0.0564.\end{aligned}\quad (\text{A9})$$

A 95% confidence interval for $\log \hat{n}$ thus runs from $\ln(2.26) - 1.96\sqrt{.0564} = 0.35$ to $\ln(2.26) + 1.96\sqrt{.0564} = 1.28$; exponentiation yields the 95% confidence interval for the estimated mean number of plots given by $e^{.35} = 1.42$ to $e^{1.28} = 3.6$ that is reported in the main text.

Expected Number of Observable Plots Accounting for End-of-Study Truncation

To model the expected number of observable (in the data) plots in progress at any time t during the study period ($\tau_s < t \leq \tau_f$) accounting for the truncation imposed by the end of the study period τ_f (30 June 2011), consider a plot that began at any time $s \leq t$. Such a plot will be observable at time t if the plot duration D falls between $t - s$ (the plot is still ongoing at time t) and $\tau_f - s$ (the plot is completed before the end of the study at time τ_f). The chance that a plot that begins at time $s \leq t$ is observable at time t thus equals $\Pr\{t - s < D \leq \tau_f - s\}$. By the Poisson plot initiation process, the rate with which plots are initiated at any time instant equals α , thus the expected number of observable plots at time t accounting for end-of-study truncation equals

$$\begin{aligned}&\int_{-\infty}^t \alpha \Pr\{t - s < D \leq \tau_f - s\} ds \\ &= \alpha \int_0^{\infty} \Pr\{u < D \leq u + \tau_f - t\} du \\ &= \alpha \left\{ \int_0^{\infty} S(u) du - \int_{\tau_f - t}^{\infty} S(u) du \right\} \\ &= \alpha \left\{ \int_0^{\tau_f - t} S(u) du + \int_{\tau_f - t}^{\infty} S(u) du - \int_{\tau_f - t}^{\infty} S(u) du \right\} \\ &= \alpha \int_0^{\infty} S(u) du \frac{\int_0^{\tau_f - t} S(u) du}{\int_0^{\infty} S(u) du} \\ &= \alpha E(D) \Pr\{D^* \leq \tau_f - t\}\end{aligned}\quad (\text{A10})$$

where the change of variable $u = t - s$ has been applied in the first line of Equation (A10), $\int_0^{\infty} S(u) du = E(D)$, and the ratio $S(x)/E(D) = f_{D^*}(x)$ is recognized as the probability density of the *remaining life* (or the *forward recurrence time*) of an ongoing plot interrupted at a random point in time.⁵ Thus, $\int_0^{\tau_f - t} S(u) du / \int_0^{\infty} S(u) du = \int_0^{\tau_f - t} f_{D^*}(x) dx = \Pr\{D^* \leq \tau_f - t\}$ as claimed. Application of this formula to the Erlang-2 distribution estimated previously was used to plot the smooth curve in Figure 3 in the main text.

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