DEVELOPING RISK METRICS TO ESTIMATE RISKS OF CATASTROPHIC BIOLOGICAL AND BIOTERRORIST EVENTS: APPLICATIONS TO THE FOOD INDUSTRY

HAMID MOHTADI

University of Wisconsin, Milwaukee, Wisconsin and University of Minnesota, Minneapolis, Minnesota

Abstract: If the food sector is attacked, the likely agents will be chemical, biological or radionuclear (CBRN). This article provides an overview of ongoing research on international terrorist/criminal activity involving such agents. The issue is the ability to calculate the likelihood of rare but catastrophic risks and in this case, the risk of a catastrophic terrorist attack. The analysis is based on using a statistical method known as *extreme value statistics* to estimate this risk. The article argues that such a method is an appropriate tool for studying high impact, low frequency events. The pronounced nonstationary patterns within the data suggest that the "reoccurrence period" for such attacks is decreasing every year. Similarly disturbing trends are evident in a broader dataset which is nonspecific as to the methods or means of attack.

Keywords: extreme value theory; catastrophic risk assessment; biological weapons; chemical weapons; food supply chain; terrorism

This article develops a data-based probabilistic algorithm for food vulnerabilities based on a statistical method known as *extreme value theory* that focuses on the distributional properties of the *maxima* or *minima* of a sequence of random variables. For the purposes

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of developing this probability metric, the focus is on intentional incidents for which food is a potential vehicle. Such incidents are broadly categorized in the literature as chemical biological and radionuclear (CBRN) events. While the food supply chain can be attacked in a number of different ways, the focus on CBRN-materials is warranted since their deliberate introduction into the civilian population is biased toward targeting the food sector's infrastructure, which provides reach across a wide region. The data are complied under a prior research project [1] funded by the Department of Homeland Security. While this data focuses on intentional CBRN events, there is a second project currently underway that aims at generalizes this data and the approach to accidental food events as well.

1 OVERVIEW

Since 2001, concern over intentional food contamination has been rising. Although the magnitude of health and human impacts or economic damage from intentional or accidental agents has not reached "catastrophic" levels, such a potential remains. For example, the World Health Organization (WHO) has been gravely concerned that food may be used as vehicle for terrorism.[1] Evidence does point to a recent rise in the severity of intentional food attacks (Figure 1). Evidence also suggests that many, if not all, food incidents have the *potential* to be intentionally caused and conversely, many known intentional food incidents may well be reported as accidental before true causes are discovered. The need to protect against such potential catastrophes requires an ability to assign risk to different events. This requires the knowledge of the likelihood of occurrence to each event. Yet, this seemingly simple task has not been possible thus far. The fact that such catastrophic events have fortunately not taken place yet, also implies the absence of hard data from which to build a probability-based risk metric framework. This poses a major stumbling block for a policy of protecting against catastrophic risk or for the developing of private risk markets for such extreme forms of risk.

The remainder of this article is organized as follows. First, data are discussed. Next, the statistical methodology is discussed. Following that, model estimation and statistical evidence on the likelihood of a catastrophic event that involves the use of CBRN material are provided. The final section contains the concluding remarks.

2 DATA AND THE OBSERVED TRENDS

2.1 Data

The data comprises of 448 observations complied from primary-source materials, internet postings, and the existing literature on CBRN-terrorist incidents.[2] The figure of 448

[1] In a (2002) report WHO states [2], "The malicious contamination of food for terrorist purposes is a real and current threat. . . The WHO and its Member States are concerned that chemical, biological or radionuclear agents might be used deliberately to harm civilian populations and that food might be a vehicle for the dissemination of such agents."

[2] The sources for the compilation of this data include reviews of recent terrorist incidents that were based on the weapons of mass destruction (WMD) database [3–6] as well as the open literature, such as Jenkins and Rubin [7], Livingstone and Arnold [8], Douglass and Livingstone [9], Hirsch [10], Mullen [11], Thornton [12], Kellen [13], Leventhal and Alexander [14], Kupperman and Woolsey [15], Kupperman and Kamen [16], Mullins [17], Purver [18], Tucker [19], Miller *et al.* [20] Carus [21], Mize [22].

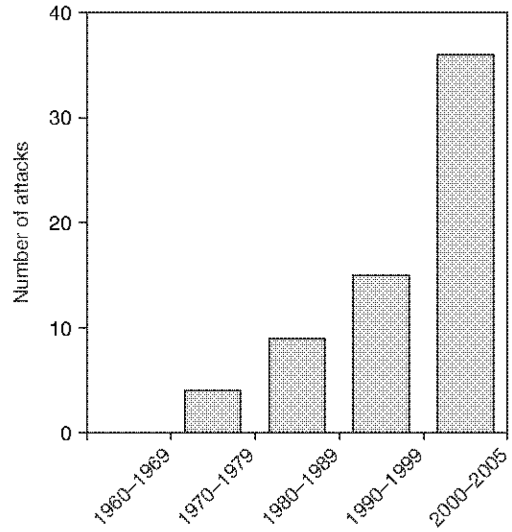

FIGURE 1 Frequency of attacks on the food or water supply.Based on authors chronology of CBRN events and the sources cited therein

does not represent the universe of all CBRN events, rather it corresponds to the subset of the most publicized, and perhaps therefore, also the most serious incidents.[3] A separate data appendix, prepared by Mohtadi and Murshid [1] which is available online at the National Center for Food Protection and Defense (NCFPD) website provides a case-by-case description of incidents in the dataset (see the URL for Mohtadi and Murshid [1]).

The chronology provides a general description of each incident, along with details on the type of agent employed and the number of casualties that resulted. The data cover a 53-year period from 1952 to 2005. However, prior to 1975 the data on CBRN-activity is particularly sparse. Unlike the Monterey Institute's WMD database, which also focuses on CBRN events, but which also includes hundreds of hoaxes and pranks that do not necessarily relate to possession with intent or actual use some hoaxes, the CBRN data that we have complied also exclude *all* hoaxes. Excluded also are accidental releases of CBRN material such as, for instance, the explosion at Union Carbide's processing plant in Bhopal, India, or the meltdown of the nuclear reactor in Chernobyl, as well as the release of weaponzied anthrax in the Soviet Union in 1978. However, *attacks* that involved a threat to the containment of CBRN material such as acts of sabotage or direct acts of violence committed on CBRN facilities *are* included. Also, another large dataset, known as the *Terrorism Knowledge Base* [maintained at the National Memorial Institute for the Prevention of Terrorism (MIPT)], reported only 56 attacks involving CBRN material, hence the need to compile this data independently.

As in the case of WMD dataset, no attempt is made to distinguish terrorism from criminal activity for at least two reasons: First, because whatever the underlying motivation behind their use, these weapons have the *potential* to do significant harm or create an atmosphere of fear and panic. Thus for instance, on September 14, 2002, when Chen

[3]Mohtadi and Murshid [23, 24] provide a detailed survey of the existing terrorism dataset and explain why the need to collect our own data arose.

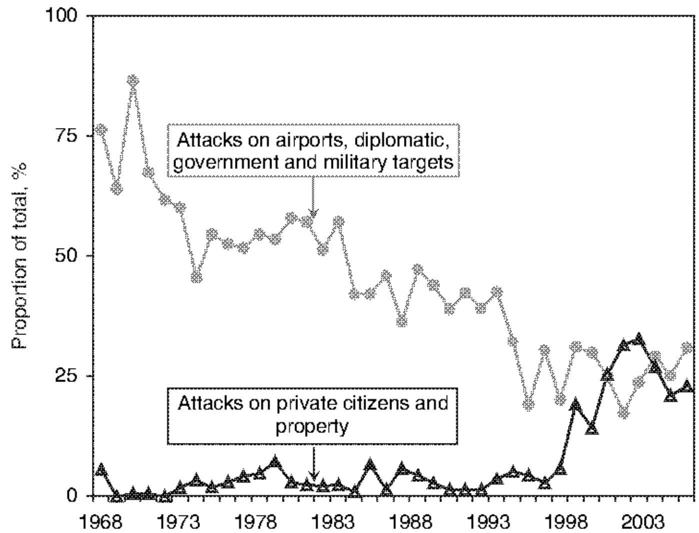

FIGURE 2 Terrorist targets, 1968–2005.MIPT, *Terrorism Knowledge Base*

Zhengping tainted his competitor's water supply and pastry dough with rat poison, the underlying motive may have been purely financial, but the incident caused 41 deaths and over 400 hospitalizations.[4] Similarly the Tylenol murders in 1982, which though not linked to terrorist activity, nevertheless created an atmosphere of fear and panic, which by itself would satisfy the definition of terrorism. Second, the use of CBRN, even when they indicate petty crimes, indicate an acceptance amongst the criminally inclined to resort to what would previously have been exotic weaponry.

2.2 Observed Trends

Evidence from the MIPT dataset indicates that there has been an increase in the severity of terrorist attacks over the past decade. For example, almost all of the incidents where mortality or injury exceeded one thousand occurred over the period from 1993 to 2006. Furthermore, it appears that the trend with respect to the choice of weaponry, targets and tactics, indicates a rise in "softer" targets such as attacks on private citizens or private property, and away from "high profile" targets such as the airlines or government and military facilities (Figure 2). To the extent that the food chain also constitutes a softer target, the same trend is observed here as well. Thus, while attacks on the food industry indicate a general rise since the 1960s, when there were no recorded attacks (Figure 2), the most dramatic increase has come since 1999, a trend which is hard to attribute to better reporting alone. Table 1 shows the CBRN attacks between 1950 and 2005 that led to at least 100 casualties.

[4]"China Deaths Blamed On Rat Poison," *CNN*, September 16, 2002, "China Masks a Mass Poisoning," *The Guardian*, September 16, 2002.

TABLE 1 A few CBRN Events with at Least 100 Injuries or Fatalities

Date	Agent	Target	Fatalities	Injuries	Description
20-Sep-1984	*Salmonella typhimurium*	Food or water supply	0	751	In September 1984, members of a religious cult known as the *Rajneeshees* contaminated salad dressing at 10 restaurants in The Dalles, a small town in Oregon, USA.
6-Sep-1987	Unknown	Police	19	140	Up to 19 members of the Philippine Constabulary died during a "fun run" in which an individual handed out bags of ice water contaminated with an unknown agent.
27-Jun-1994	Sarin	Private citizens and property	7	500	In June 1994, members of the *Aum Shinrikyo* released sarin gas in Matsumoto, Japan; 7 people died and approximately 500 more were hospitalized.
20-Mar-1995	Sarin	Private citizens and prop-erty/transportation	12	5500	On March 20, 1995, one of the deadliest terrorist attacks in history was carried out on the Tokyo subway, by *Aum Shinrikyo*; 12 people died in the sarin-gas attack and over 5500 required treatment.
8-Mar-1999	Nitric acid	Food or water supply	0	148	In March 1999, 148 persons were poisoned by nitric acid placed in the food of a restaurant in Luoyang City, China.
5-Apr-2001	CS gas	Educational Institution	Unknown	132	An unknown group attacked schools using CS gas in the Central Highlands, Vietnam; 132 people were treated for ailments—headaches and breathing problems.
8-Aug-2001	Rat poison	Food or water supply	0	120	120 patrons in 16 restaurants became ill after eating noodles that had been contaminated with rat poison in Ningxiang, Hunan Province, China.
14-Sep-2002	Rat poison	Food or Water Supply	41	400	41 people died and 400 became ill after buying breakfast food from a fast-food shop in Tangshan, Nanjing, China.
31-Dec-2002	Nicotine	Food or water supply	0	111	111 people in Byron, USA, fell ill after eating the meat that had been contaminated by a supermarket employee, Randy Jay Bertram, with an insecticide known as *Black Leaf 40*.
23-Sep-2003	Rat poison	Food or water supply	0	241	241 students and staff at the Changhu Township Center Elementary School in Yueyang, Hunan Province, China were poisoned.

[a]Source: Based on Mohtadi and Murshid's [1] chronology of CBRN events and the sources cited therein.

While there have been attacks on our food and water supply that have involved the use of conventional weapons, there is no reason in particular why terrorists should favor the food supply chain over other potential targets when using such conventional means of attack. The real threat as far as the food chain is concerned is likely to come from chemical, biological or radionuclear contaminants, which can exploit an already present distribution network to maximize the potential for disruption. Of the 448 biological, chemical and radiological incidents that have been recorded, 75 involved either a direct attack or a plan to attack the food or water supply chains.[5]

3 METHODOLOGY

Existing food protection efforts have ignored the role of probabilities and instead prioritized investments solely on severity. For example, data on health costs from food contaminations are estimated by the Economic Research Service, United States Department of Agriculture (USDA), and used by various agencies for public policy. This amounts to the implicit assumption that all catastrophic events are equally likely which is a gross error, leading to massive resource misallocation.

The method proposed here addresses this major gap. It does so by invoking the statistical properties of certain distributions, known as *extreme value distributions*, which allow us to use data on ordinary food poisoning events to deduce the probability of large catastrophic events. In effect, information about the "body" (modal part) of these distributions, allows us to extrapolate to the probabilities of catastrophic events that belong to the ***"tail"*** of these distributions.

The key insight explores the limiting behavior of the maxima, M_n, of a sequence$\{X_n\}$ of independent random variables with common distribution$F(x)$. At the heart of extreme value theory is the *extremal types theorem* [25, 26], which states if the maxima of sequences of observations converge to a nondegenerate law, $G(.)$, then$G(.)$ belongs to the class of generalized extreme value distributions (GEV):[6]

$$G_\xi(x) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\};\ 1+\xi\left(\frac{x-\mu}{\sigma}\right) \geqslant 0 \qquad (1)$$

where μ is a *location* parameter, σ is a *scale* parameter and ξ is the *shape* parameter that determines the sub-class of distribution from which our observations are drawn. Specifically, $\xi > 0$, $\xi < 0$, and $\xi = 0$ correspond to the Fréchet (heavy tailed), Weibull (bounded tailed), and Gumbel (light tailed) distributions, respectively. The GEV-representation is particularly useful, since it bypasses the need to identify the specific type of distribution to which the extreme value limit law belongs. Instead standard statistical methodology from parametric estimation can be applied to identify the parameters of interest. Other than the work by Mohtadi and Murshid [23], there has been one other study that uses this approach for terrorism data [28], but the authors use the MIPT data, not data based on

[5]We define attacks on the food or water supply as any attack that involves tampering with food and beverages with the potential to create large scale casualties. Thus for instance, simple targeted poisonings that are directed at one or perhaps a few specific individuals are not considered an attack on the food chain. However, the incident where contaminated water was handed to Filipino soldiers that led to 19 fatalities and 140 injuries is considered an attack on the food chain. We also regard attacks on livestock or the animal population in a separate category. Attacks on drugs and medication were also considered separately.

[6]See, for example, Coles [27]

CBRN events. A related article by Johnson et al. [29] studies the distribution of fatalities in two recent conflicts and show that these distributions follow a power law relationship that has a similar functional structure to the GEV distributions here.

Implicit in the approach adopted here is the assumption that the current experience with CBRN attacks is a good predictor of future CBRN terrorism. While the use of past data to forecast future trends is a common practice, the threat from CBRN weapons is likely to be dynamic as possibly unstable, as terrorists' actions are likely to be a function of an earlier counter-terrorist response by the government and *vice versa* ([30]). Yet, it is difficult to imagine how the pattern of response and counter-response could change overnight. If, as is more likely, the dynamics of this process are gradual, an analysis of data can shed important light on the current capabilities of terrorists in addition to highlighting trends in their usage.

4 MODEL ESTIMATION

The variation in CBRN dataset is rather limited as the overwhelming majority of attacks failed to cause death or injury. Nevertheless, there is some structure in the tails of the distribution coinciding with certain prominent cases, such as the *sarin* attacks in Japan and the *Rajneeshee* incident in Oregon. CBRN events, however, have apparently caused more injury than death. Following the *sarin* attack in Tokyo, for instance, roughly 5000 affected individuals needed medical treatment, whereas only 12 fatalities were reported. The largest CBRN-related fatalities occurred in Uganda, in which a cult was suspected of poisoning its members with sulfuric acid. Even here, the total number of deaths stood at 200, which pales when compared to the nearly 3000 deaths on September 11. Thus to maximize the variation in the dataset, casualties and injuries are added together. In addition, data prior to 1975 are omitted, since they are very sketchy.

The application of extreme value theory typically involves "blocking" the data into disjoint subperiods of equal length and fitting a GEV distribution to the block maxima. In setting the block size, researchers face a trade-off. "Blocking" too narrowly threatens the validity of the limiting argument, leading to a bias in estimation. Wider blocks, however, will generate fewer maxima, leading to greater variability in our estimates. This article opts for semiannual blocking as this choice seems to provide a reasonable trade-off between bias and variance.

The analysis detailed elsewhere [23, 24], allows for both time trends in the location parameter μ and the scale parameter σ, as well as breakpoints in the data. Dummy variables for the data breakpoints included 1980–1905 dummy, 1990–2005 dummy and post-1990 dummy. Based on a combination of the quantile–quantile (QQ) plots and maximum likelihood estimates, the best results are reported as shown in Table 2. These results indicate evidence of trend behavior in the severity of the attacks, as seen by the significance both in the location parameter μ and the scale parameters, σ. This is consistent with an increasing number of casualties resulting from the worst attacks each year. However, the fact that the value of the estimated shape parameter, ξ, is positive and significant in both models suggests that trend is not all that is at work and that at least some of the extreme variation in the data *must* be explained by the *heavy-tailed* nature of the underlying stochastic model.

4.0.1 Forecasting Probability of Attacks Based on our estimated two models reported in Table 2, one can calculate the probability of a CBRN attack of various magnitudes

TABLE 2 GEV Parameter Estimates Fitted to CBRN Data

		–	–
μ	Constant	0.0096	0.0227
		(0.00)	(0.01)
	Trend	0.0103	0.0227
		(0.00)	(0.01)
	1980–1905 dummy		
	1990–2005 dummy		
	Post-1990 trend		0.0267
			(0.03)
	Post-1994 trend		
		–	–
σ	Constant	0.0168	0.0357
		(0.01)	(0.00)
	Trend	0.0183	0.0365
		(0.01)	(0.00)
ξ		1.1979	0.5446
		(0.24)	(0.19)
Negative log likelihood		94.6	99.3

[a]Estimation was done in *R* using the **Introduction to Statistical Modeling of Extreme Values** (ISMEV) package. The ISMEV package is based on software written by Stewart Coles. Estimates are based on the log of the maximum number of fatalities and injuries over a six month period. Standard errors are reported in parentheses. The last row reports the negative log likelihoods for each model.

TABLE 3 Probability of CBRN and non-CBRN Attacks of Various Severities

1000	Current risk	0.31	0.40
5000		0.27	0.31
10,000		0.25	0.28
1000	5-year forecast	0.34	0.47
5000		0.30	0.38
10,000		0.28	0.34
1000	10-year forecast	0.37	0.54
5000		0.32	0.44
10,000		0.31	0.41
1000	20-year forecast	0.42	0.67
5000		0.37	0.56
10,000		0.35	0.52

[a]The two columns report probabilities of CBRN events of various magnitudes within any given year, corresponding to the two parameter estimates of the two columns in Table 2, respectively.

and time horizons. These estimates are provided in Table 3. The results suggest that the probability of a large CBRN attack, defined as an attack that inflicts between 1000 and 10,000 casualties (injury or death), is nonnegligible. Using the estimates for the second column of table 2, which provided the best fit to the data, the likelihood that a CBRN attack (anywhere in the world) causes 1000 or more casualties is 0.40. As noted above, the distribution of CBRN events is characterized by pronounced tails. Consequently the current probability of a 10,000-casualty event is not much lower. Using the specification in Table 2, this value works out to be 0.28.

Obviously, these results are sensitive to how one models extreme variations in the data. Thus, if one believes that extreme observations, post-1990s, are better captured by a right shift of the location as opposed to scale parameter, then the current risk of an event leading to 10,000 casualties is relatively low—somewhere between 0.05 and 0.10 (not reported here). However by implication, a continuation of these trends would imply that the future risk of a large event would be much higher. These values probably also overestimate the risk. In short, in whatever way, we choose to model the distribution of casualties from CBRN events, the presence of a nonstationary component is undeniable. As a result, the *recurrence* (return) period of these events is expected to decline with time.

5 CONCLUSION

This short article presents an overview of the ongoing research into the assessment of the risk of bioterrorism in the food sector. The analyses are based on nearly 450 observations from 1950 to 2005, but with a focus on the 1975–2005 period. The focus is on intentional and terrorist events at a global scale involving chemical, biological or radionuclear agents, agents that are especially likely to be associated with the food sector as the channel for their dissemination. The analytical method for assessing this risk derives from a statistical technique known as extreme value theory that is tailored to the estimation of "tail" probabilities for rare but catastrophic events. It has been applied to financial crisis, to earthquake predictions and to weather patterns. This study is one among the first efforts to also apply this to terrorism events. In our other articles, another data set (MIPT) consisting of over 25,000 observations were also used as a benchmark to compare the risk of terrorism in the food sector with terrorism at large.

The findings are somewhat alarming. For example, if we focus on catastrophic CBRN events, that is those with large numbers of casualties, we see a rise in their severity. Correspondingly, the average reoccurrence period for such attacks is on the decline, while their probability is on the rise as time goes by. Similar trends underline the findings with respect to terrorist attacks more generally that were documented elsewhere. Since food is a prime candidate for CBRN agents, the implication of this finding is self-evident. By quantifying such risks, this line of research has opened a path toward rationalizing the private and public sector decisions involving extreme risk forms, including both the public policy for ranking risk mitigating strategies and the also the development of private risk markets for catastrophic forms of risk.

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