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Risk Analysis of Urban Dirty Bomb Attacking Based on Bayesian Network

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Abstract: Urban dirty bomb attacking is a type of unconventional terrorism threatening the urban security all through the world. In this paper, a Bayesian network of urban dirty bomb attacking is established to analyze the risk of urban dirty bomb attacking. The impacts of factors such as occurrence time, location, wind fields, the size of dirty bomb, emergency response and defense approaches on casualty from both direct blast and radiation-caused cancers are examined. Results show that sensitivity of casualty from cancers to wind fields are less significant; the impact of emergency response on the direct casualty from blast is not large; the size of the dirty bomb results in more casualties from cancers than that from bomb explosions; Whether an attack is detected by the police is not that related to normal or special time, but significantly depends on the attack location; Furthermore, casualty from cancers significantly depends on the location, while casualty from blast is not considerably influenced by the attacking location; patrol and surveillance are less important than security check in terms of controlling the risk of urban dirt bomb, and security check is the most effective approach to decreasing the risk of urban dirty bomb.

Keywords: risk analysis; dirty bomb; Bayesian network; terrorism

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1. Introduction

Urban dirty bomb attacking is a type of unconventional terrorism. At the onset of an attack, the attacker would use a radiological dispersal device (RDD), containing radioactive materials which can be released from an explosion and transported to other areas by wind. Due to the difficulty of obtaining, storing and transporting the radioactive material and creating the dirty bomb, it seems unachievable to successfully make a terrorist dirty bomb attack, especially in urban areas where security conditions are often better than rural areas. In fact, based on the global terrorism database (GTD) [1], no successful dirty bomb attacking has been reported.

Although the shocking 11 September 2001 terrorist attack didn't include radioactive material, Bin Laden had attempted to conduct dirty bombs into this event [2], and there were also several similar incidents recorded in GTD. There is no doubt that a terrorist dirty bomb attack can lead to more devastating consequences for the public, government, society and economy than other types of terrorist attacks. Besides direct blast from TNT, people can also be injured and even killed by release of radioactive materials, which may cause cancer or other diseases. Thus, people often have great fear of radiations in such kind of events. The desolate and uninhabited ruins caused by the pollution of radioactive materials in the Chernobyl and Fukushima nuclear accidents are the best examples [3]

However, that no successful attacks have happened doesn't mean no attempt to make a dirty bomb attack. This is significant for us to try to do research on urban dirty bomb attack.

2. Related Work

Many previous studies [4–7] focused on dirty bomb attacking. Rosoff and Winterfeldt used a combination of several risk analysis tools to assess the consequences of attacks, including human health and economic impacts, but without considering the impacts of policing [8]. Jeong et al. assessed the potential impacts of radioactive terrorist attacks on human health assuming drinking water was contaminated by radioactive terrorist attacks in the metropolitan area of Seoul, Korea [9]. Jeong et al. also assessed the potential and actual effects on human health from an inhalation event due to a radiological terrorist attack in the same area by both Gaussian and CFD modelling [10]. Similarly, Reshetin used a Gaussian model to estimate the maximum inhalation doses, the spatial extent and radioactivity of contamination within an urban area after the initial dispersion of ^{90}Sr radiological dispersion device (dirty bomb) in a terrorist activity [11]. Andersson et al. used a decision support system ARGOS, which is able to estimate the consequences of terror attacks involving chemical, biological, nuclear and radiological substance, to calculate the dose contributions from contaminants dispersed in the atmosphere after a 'dirty bomb' explosion [12]. Hu et al. proposed an assessment method of radiation dose in terrorist dirty bomb attacks based on WRF, which is developed by implementing the radioactive decay process into source term and ground dry and wet deposition [13].

It is obvious that most of the previous studies focused on radiation dose estimation based on numerical simulation methods, often examining the distribution of potential radiological materials in a dirty bomb attacking. However, few research studied the impacts of environmental and social factors on the occurrence probability and the consequences of urban dirty bomb attacking.

Thus, we try to study how environmental and social factors influence the probability of the risk happening and consequences of urban dirty bomb attacking by Bayesian Network (BN), it is adopted in the paper to evaluate the occurrence probability and the consequences of urban dirty bomb attacking since it has certain advantages in the representation of complex relation, uncertain probabilities and causal relationship.

In fact, Bayesian network has been widely applied in many fields. In the field of network security, Bayesian network was used to assess the online public opinions and to predict the interactive relationship among different people [14]; In the field of emergency management, Bayesian network model was constructed to predict emergencies and to assess the main states and loss consequences [15]; In the field of fault diagnosis, Bayesian network (BN) is increasingly utilized in fault diagnosis to effectively deal with various uncertainty problems [16]. Bayesian network model was integrated with event tree and other models to investigate emergency response experiences contained in massive emergency cases [17]; A dynamic-Bayesian-network-based evaluation methodology was used to predict the resilience value of an engineering system [18]. Bayesian network was also used to analyze the usual causes of failures and the dependencies among the variables in dust explosion scenarios [19]; Similarly, it turned out to be effective that the scenario analysis was combined with Bayesian network to evaluate the occurrence probability of mine water inrush accident and the hazard evolution, performing the disaster response [20]. Bayesian network can also construct and verify the reliability of the model and be used in the procedures of automatic creation of conditional probability tables [21,22]. Furthermore, Fu et al. proposed a method that combined Bayesian network with the principle of case suitability to make early warning on terrorist attacks [23]. Pat-Cornell and Guikema proposed a model for setting priorities among threats and countermeasures based on probabilistic risk analysis, decision analysis, and elements of game theory [24]. The literature above shows that Bayesian network has certain feasibility and validity in solving uncertain problems.

In this paper, a Bayesian network of urban dirty bomb attacking is established based on cases studies and expert judgments to examine how wind fields, size of dirty bomb, emergency response and defense approaches affect the casualty caused by both direct blast and cascading cancers. In this paper, the Tai-Yang-Gong area in Chaoyang District of Beijing (TYG) is selected as the research object, and the experts in the police station of the Tai-Yang-Gong area in Chaoyang District of Beijing (TYG police station) also provide several judgments for establishing the Bayesian network. The reason why the TYG area is chosen as a target subject is that the TYG area with a high population density has a relatively high crime rate in Beijing despite the good policing conditions. Moreover, in this area, there are different types of targets including shopping malls, residential areas, parks, schools, hotels etc. Thus, it is typical for the risk analysis of urban bomb attacking as well as investigation of the impacts those main factors may have on this kind of event.

3. Methodology and Data Sets

3.1. Bayesian Network Building

Bayesian Networks are joint probability distributions between multiple variables expressed as directed acyclic graphs consisting of a set of nodes, a set of edges, and conditional probability tables [25], and there are normally three steps to build a Bayesian network.

Firstly, determining the Bayesian network node variables and their state classification, which could take advantage of case studies and expert judgments, especially for the problems that are not of massive occurrences and detailed records. The nodes in the network represent the factors which can influence the event. Classifying different states of nodes may have different influences on other nodes.

Secondly, confirming the structure of Bayesian network, i.e., the casual relationship of Bayesian network nodes. The casual relationship is represented by a set of directed edges, and the direction is pointed from parent nodes to child nodes. The casual relationship of the Bayesian network is determined by data samples for Bayesian network structure learning when enough historical data samples are available, while the structure of Bayesian network is usually determined by expert judgments when useful data samples are inadequate.

Thirdly, determining the conditional probabilities of all nodes. The prior probability of parent nodes should be determined in the conditional probability tables at the beginning, and it is often based on experts' experience or real data. The probabilities of events represented by child nodes are only influenced by the probabilities of events represented by parent nodes, thus the parameter adjustment of parent nodes would result in probability changes of child nodes. In this step, some machine learning algorithms or expert judgments weighted by the Demptster-Shafer evidence theory are conducted to obtain the conditional probabilities [26,27].

After finishing the steps above, the Bayesian network with conditional probabilities can be established to analyze target problems.

In this paper, we establish the Bayesian network (as shown in Figure 1) with 13 basic nodes by combining previous studies and experts' experience. With this Bayesian network, the evolution of urban dirty bomb attacking can be presented in detail. Each Bayesian network node is described as follows:

A. Time. The occurrence time of dirty bomb attacking can be classified into two states according to the expert system in the TYG police station, which are 'normal time' and 'special time'. Special time refers to Spring Festival, National Day and other holidays when crime incidents are expected to increase and security check, surveillance and patrol are to be enhanced, while on normal time the security level is lower, and dirty bomb attackers may easily determine a proper place and fix some time to explode the bomb.
B. Location. In the TYG area, urban dirty bomb attacking may occur at three different types of places, which are 'business quarter', 'residential quarter' and 'open space', corresponding to the three states of this node. Obviously, locations with different population density may have different demands for police deployment.
C. Security check. Security check aims to find contraband and dangerous persons by checking people or vehicles in the TYG area. According to experts in the TYG police station, security check is classified into two states, which are 'yes' and 'no'.
D. Surveillance. Surveillance means monitoring the specific areas by Closed-Circuit Televisions (CCTV) and sending relevant image or video data to the police, assessing the security condition

for public. Experts in the TYG police station argue that surveillance have two states, which are '24-h-covering' and 'non-24-h-covering'.

E. Patrol. Patrol refers to the fact that police walk around the area to check which parts are out of trouble or danger. Experts in the TYG station point out that there are two types of patrol states in terms of patrol frequency, that is, '>2 times' and '<2 times'.

F. Population density. The Geographic Information System (GIS) of Beijing shows three types of population density, namely, 'more than 1000 persons/km^2', '500 to 1000 persons/km^2', and 'less than 500 persons/km^2'. Population density directly influences casualty from bomb blast since the area with high population density may see the increasing risk of serious casualties.

G. Wind speed. Wind speed is one of the direct factors influencing the casualty from cancers. Based on the meteorological data (2014–2016, rp5: http://rp5.ru/), wind speed is divided into 4 main states, which are 'less than 2 m/s', '2 m/s to 4 m/s', '4 m/s to 6 m/s' and 'more than 6 m/s'.

H. Wind direction. For wind direction, there are three main directions, namely, 'east', 'north' and 'northeast' based on meteorological data (2014–2016) from rp5 website.

I. Size of dirty bomb. 'TNT > 45 kg & Pu > 5 kg' and 'TNT < 45 kg & Pu < 5 kg' are two main types when it comes to the size of dirty bomb. The size of dirty bomb directly influences the degree of casualties from both bomb blast and cancers.

J. Police detection. 'Yes' and 'No' are general answers to the question whether dirty bomb can be detected.

K. Emergency response. From the perspective of timing, government, police and other organizations generally have 'on time' or 'delay' emergency responses to urban dirty bomb attacking.

L. Casualty from cancers. Casualty from cancers is an important indicator to evaluate the consequences of urban dirty bomb attacking. Based on the Production Safety Accident Report, the Investigations and Handling Rules, China, simultaneously simulated by the software HotSpot (established by Department of Energy, Office of Emergency Operations and Lawrence Livermore National Laboratory (LLNL), and used for safety-analysis of DOE facilities handling nuclear material) [28], casualty from cancers has three types of representation, that is 'less than 10 deaths or less than 50 injured', '11 to 30 deaths or 51 to 100 injured' and 'more than 30 deaths or more than 100 injured'.

M. Casualty from blast. Casualty from blast has the same classification criteria as casualty from cancers, i.e., "less than 10 deaths or less than 50 injured", "11 to 30 deaths or 51 to 100 injured" and "more than 30 deaths or more than 100 injured".

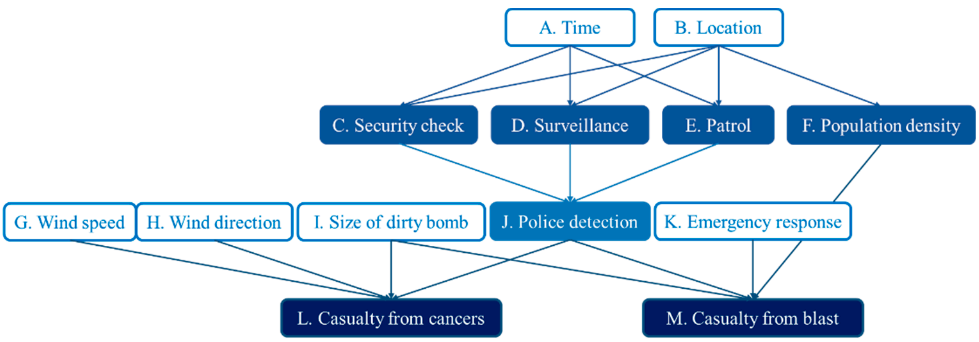

Figure 1. Bayesian network of urban dirty bomb attacking.

3.2. Probability Distribution of Bayesian Network Nodes

The Dempster-Shafer evidence theory first proposed by Dempster and developed by Deutsch and Yager and Liu further [26,27], can be used to deal with uncertain information. To deduce the lack of stability in the posterior probability estimation of the conditional probability table (CPT) in the Bayesian network based on experts' practice, we introduce the evidence theory to analyze the expert scoring.

Since expert system is one of the most effective approaches to the problem of insufficient historical statistics, we collect the probabilities by questionnaire from experts. In this step, four experts' judgement data are processed by Dempster-Shafer evidence theory.

The Dempster-Shafer evidence method defines a frame of discernment and the Mass function, but the Mass function needs to meet the following conditions:

$$\begin{cases} m(\phi) = 0 \\ \sum\limits_{A \subseteq \Theta} m(A) = 1 \end{cases} \tag{1}$$

where $m(A)$ is the Mass function of event A, which is also the basic probability function of discernment Θ. The synthesis rule of Dempster-Shafer evidence is shown in Equation (2).

$$m(A) = \begin{cases} \frac{1}{K} \sum\limits_{A1 \cap A2 \cap \ldots \cap A_N} m_1(A_1) \cdot m_2(A_2) \cdot \ldots m_N(A_N), A \neq \phi \\ 0, A = \phi \end{cases} \tag{2}$$

where, m_1, m_2, … , m_N are the basic probability functions of discernment Θ, and K represents the conflict degree among m_1, m_2, … , m_N, which is calculated as follows:

$$K = \sum_{A1 \cap A2 \cap \ldots \cap A_N \neq \phi} m_1(A_1) \cdot m_2(A_2) \cdot \ldots m_N(A_N) = 1 - \sum_{A1 \cap A2 \cap \ldots \cap A_N = \phi} m_1(A_1) \cdot m_2(A_2) \cdot \ldots m_N(A_N) \tag{3}$$

Take the Node C i.e., "security check" for example. The prior probability distribution of "security check" depends on the combination of "Time" and "Location", and its probability distributions respectively given by four experts are shown in Table 1. $m_1(1, 2)$, … , $m_4(1, 2)$ represent the probability distributions given by four experts, where $m_1(1, 2)$ with the value (0.5, 0.5) means that the first expert thought the probability of "security check" is 0.5 on the premise that the combination of time and space are "normal time" and "business quarter", and the probability of no "security check" is also 0.5. Based on Equations (2) and (3), the prior probability of "security check" is calculated as follows: $K = m_1(A_1) \cdot m_2(A_1) \cdot m_3(A_1) \cdot m_4(A_1) + m_1(A_2) \cdot m_2(A_2) \cdot m_3(A_2) \cdot m_4(A_2) = 0.22$, $m(A_1) = (1/K) \cdot m_1(A_1) \cdot m_2(A_1) \cdot m_3(A_1) \cdot m_4(A_1) = 0.982$.

Just like as has been presented above, we use Dempster-Shafer evidence theory to deal with the judgement data from different experts to determine the conditional probabilities of other nodes.

Table 1. States of Bayesian nodes.

Nodes	States of Bayesian Nodes	Basis
A. Time	(1) normal times; (2) special times	Experts' experience
B. Location	(1) business quarter; (2) residential quarter; (3) open space	Experts' experience
C. Security check	(1) yes; (2) no	Real working time and location of CCTVs; check points and patrolling of TYG police office
D. Surveillance	(1) 24-h-covering; (2) not 24-h-covering	
E. Patrol	(1) >2 times; (2) <2 times	
F. Population density	(1) >1000/km^2; (2) 500~1000/km^2; (3) <500/km^2	GIS (distribution of Beijing population density)
G. Wind speed	(1) $\leq$2 m/s; (2) 2 m/s~4 m/s; (3) 4 m/s~6 m/s; (4) >6 m/s	The meteorological data (2014~2016) from rp5 website
H. Wind direction	(1) east; (2) north; (3) northeast	The meteorological data (2014~2016) from rp5 website
I. Size of dirty bomb	(1) TNT > 45 kg & Pu > 5 kg; (2) TNT < 45 kg & Pu < 5 kg	Experts' experience
J. Police detection	(1) yes; (2) no	Experts' experience
K. Emergency response	(1) on time; (2) delay	Experts' experience
L. Casualty from cancers	(1) less than 10 persons (less than 50 injuries); (2) 11 to 30 persons (51 to 100 injuries); (3) more than 30 persons (more than 100 injuries)	Simulated by hotspot; also by expert system; The Production Safety Accident Report, the Investigations and Handling Rules, China
M. Casualty from blast	(1) less than 10 persons (less than 50 injuries); (2) 11 to 30 persons (51 to 100 injuries); (3) more than 30 persons (more than 100 injuries)	Experts' experience; The Production Safety Accident Report, the Investigations and Handling Rules, China

4. Results and Discussions

In this study, we examine the sensitivities of consequences of urban dirty bomb attacking to different factors based on different states of Bayesian network nodes, assessing the impacts of different factors on risk happening and potential casualties in attacking activities. Then we evaluate the effectiveness of the defense approaches, namely security check, surveillance and patrol for decreasing the risk happening of urban dirty bomb attacking and the casualties from both direct explosion and cancers. As shown in Table 2, those sensitivity cases are carried out.

Table 2. Experts' judgmental data and the final condition probabilities of the node.

Causal Relationship Element		Experts' Judgement				Calculated Results
Time	Location	m1 (1, 2)	m2 (1, 2)	m3 (1, 2)	m4 (1, 2)	m(T) of Security check
normal times	business quarter	(0.5, 0.5)	(0.6, 0.4)	(0.8, 0.2)	(0.9, 0.1)	0.982
normal times	residential quarter	(0.3, 0.7)	(0.4, 0.6)	(0.7, 0.3)	(0.9, 0.1)	0.857

4.1. Sensitivity of Casualty to Wind Fields, Size of Dirty Bomb and Emergency Response

The upper left panel of Figure 2 shows the casualties from cancers under 6 different wind fields namely GH1~3 and GH7~9. As can be seen there, casualty in case GH3 (with the wind speed $\leq$2 m/s and the wind direction as northeast) is larger than that in other cases, which is consistent with the result in [28]. However, the small differences (about $\pm$20%) of casualty among all the six cases suggest that the sensitivity of casualty from cancers to wind fields is less important.

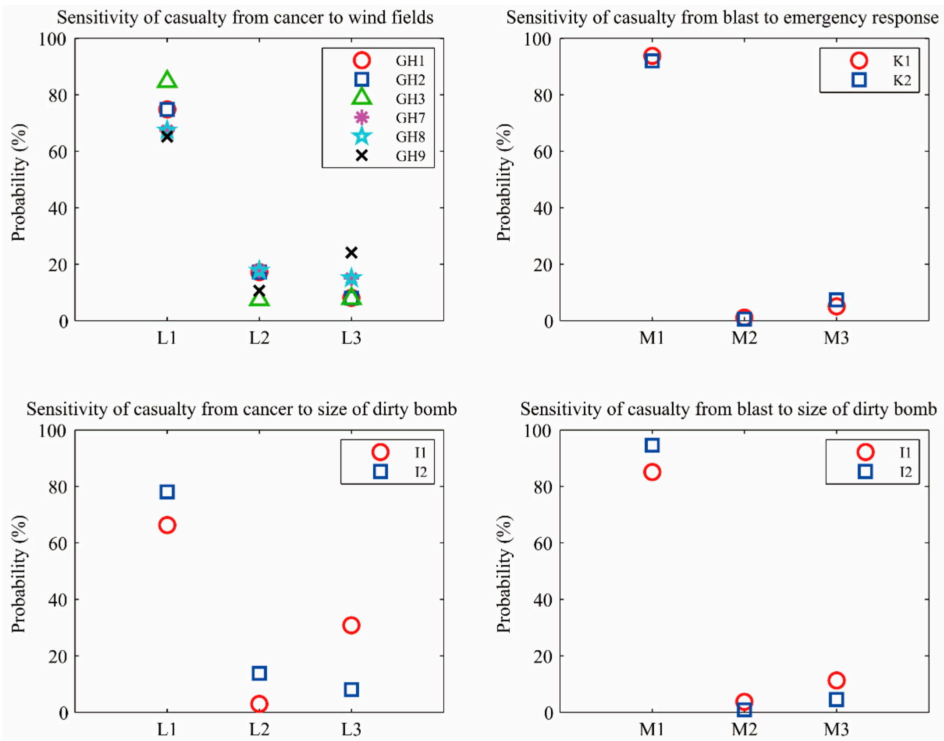

Figure 2. Sensitivity of casualty to wind fields, the size of dirty bomb and emergency response.

The upper right panel of Figure 2 shows the casualties from bomb explosions when emergency response is on time (K1) and delayed (K2), respectively. As shown in this panel, the casualties from bomb explosions are not significantly affected by the state of the node 'Emergency response', since the differences of casualty between K1 and K2 for M1, M2 and M3 are quite small (lower than 5%). This result indicates that though on-time emergency response can decrease the mass casualties (e.g., M3), the impact of emergency response on the direct casualties from blast is not large.

The lower panels of Figure 2 show how "the size of dirty bomb" affects the casualties from both bomb explosion and cascading cancers. From these two panels, we can see that larger bombs may cause heavier casualties especially from cascading cancers. As shown in the lower left panel, the bomb with 'TNT > 45 kg & Pu > 5 kg' (case I1) will lead to about 20% more casualties from cancers than that with the size of 'TNT < 45 kg & Pu < 5 kg' (case I2). However, the difference of casualty from bomb blast between I1 and I2 is not that large.

4.2. Impacts of Occurrence Time and Location on Risk Happening and Attacking Consequence

To examine when and where a dirty bomb attacking is more likely to happen (whether it is detected by the police or not), and to investigate the impacts of its occurrence time (node A) and location (node B) on attacking consequences (node L and M), sensitivity studies are conducted by setting 6 different cases (AB1~6). As shown in Table 3, cases AB1~3 represent the occurrence on normal time in business quarter, residential quarter and open space, while cases AB4~6 represent the occurrence on special time corresponding to the same locations. The results of estimated probabilities calculated by the Bayesian network are shown in Table 4.

Table 3. Description of sensitivity cases.

Case	Node	Description
AB1	A. Time & B. Location:	Time = 'normal times'; Location = 'business quarter'
AB2	A. Time & B. Location:	Time = 'normal times'; Location = 'residential quarter'
AB3	A. Time & B. Location:	Time = 'normal times'; Location = 'open space'
AB4	A. Time & B. Location:	Time = 'special times'; Location = 'business quarter'
AB5	A. Time & B. Location:	Time = 'special times'; Location = 'residential quarter'
AB6	A. Time & B. Location:	Time = 'special times'; Location = 'open space'
C1	C. Security check	Security check = 'yes'
C2	C. Security check	Security check = 'no'
D1	D. Surveillance	Surveillance = '24-h-covering'
D2	D. Surveillance	Surveillance = 'not 24-h-covering'
E1	E. Patrol	Patrol = '>2 times'
E2	E. Patrol	Patrol = '<2 times'
F1	F. Population density	Population density = '>1000/km^2'
F2	F. Population density	Population density = '500~1000/km^2'
F3	F. Population density	Population density = '<500/km^2'
GH1	G. Wind speed & H. Wind direction	Wind speed = '≤2 m/s'; Wind direction = 'east'
GH2	G. Wind speed & H. Wind direction	Wind speed = '≤2 m/s'; Wind direction = 'north'
GH3	G. Wind speed & H. Wind direction	Wind speed = '≤2 m/s'; Wind direction = 'northeast'
GH4	G. Wind speed & H. Wind direction	Wind speed = '2 m/s~4 m/s'; Wind direction = 'east'
GH5	G. Wind speed & H. Wind direction	Wind speed = '2 m/s~4 m/s'; Wind direction = 'north'
GH6	G. Wind speed & H. Wind direction	Wind speed = '2 m/s~4 m/s'; Wind direction = 'northeast'
GH7	G. Wind speed & H. Wind direction	Wind speed = '>4 m/s'; Wind direction = 'east'
GH8	G. Wind speed & H. Wind direction	Wind speed = '>4 m/s'; Wind direction = 'north'
GH9	G. Wind speed & H. Wind direction	Wind speed = '>4 m/s'; Wind direction = 'northeast'
I1	I. Size of dirty bomb	Size of dirty bomb = 'TNT > 45 kg & Pu > 5 kg'
I2	I. Size of dirty bomb	Size of dirty bomb = 'TNT < 45 kg & Pu < 5 kg'
J1	J. Police detection	Police detection = 'yes'
J2	J. Police detection	Police detection = 'no'
K1	K. Emergency response	Emergency response = 'on time'
K2	K. Emergency response	Emergency response = 'delay'
L1	L. Casualty from cancers	less than 10 persons (less than 50 injuries)
L2	L. Casualty from cancers	11 to 30 persons (51 to 100 injuries)
L3	L. Casualty from cancers	more than 30 persons (more than 100 injuries)
M1	M. Casualty from blast	less than 10 persons (less than 50 injuries)
M2	M. Casualty from blast	11 to 30 persons (51 to 100 injuries)
M3	M. Casualty from blast	more than 30 persons (more than 100 injuries)

Table 4. Estimated probabilities with different occurrence time and location.

Bayesian Nodes	State of Bayesian Nodes	Estimated Probabilities					
		AB1	**AB2**	**AB3**	**AB4**	**AB5**	**AB6**
J. Police detection	J1	0.995	0.895	0.040	0.998	0.992	0.195
	J2	0.005	0.105	0.960	0.003	0.008	0.805
L. Casualty from cancers	L1	0.988	0.921	0.357	0.989	0.986	0.459
	L2	0.010	0.046	0.360	0.009	0.011	0.303
	L3	0.003	0.032	0.283	0.002	0.004	0.238
M. Casualty from blast	M1	0.993	0.911	0.933	0.995	0.991	0.943
	M2	0.002	0.005	0.028	0.002	0.002	0.024
	M3	0.005	0.085	0.039	0.003	0.007	0.033

As can be seen in Table 3, police detection is not that related to normal or special time. For example, the probability of J1 will only increase from 0.995 to 0.998 if the state turns from normal time (AB1) to special time (AB4) in business quarter.

However, the probability of police detection significantly depends on the location. For instance, the probability of J1 (Police detection = 'yes') decreases from 0.995 at AB1 to 0.04 at AB3, indicating that if the occurrence location turns from business quarter to open space (on normal time), the probability of risk happening will remarkably increase. At both normal and special times, open space has the lowest probability of police detection since security, surveillance and patrol in open space are of lower intensity than those in business quarter or residential quarter.

If the occurrence location turns from business quarter or residential quarter to open space at both normal and special times, the probability of more than 30 casualties (more than 100 injuries) from cascading cancer will increase from lower than 0.01 to higher than 0.2. This indicates that casualty from cascading cancer significantly depends on the location. On the other hand, casualty from bomb blast is not considerably influenced by the location. The reason may be that in open space, though the probability of police detection is extremely low, the population density is very low (probability of "lower than 500/km^2" is higher than 0.99), which also affects the casualty from bomb blast.

4.3. Evaluation of the Defense Approaches

To protect people from being attacked by a dirty bomb and to decrease casualties and injures in attack activities, generally, security check, surveillance and patrol are done by the police. In this paper, we evaluate these three approaches by using Bayesian network. As shown in Figure 3, eight combinations based on the three approaches are tested to examine the performance of the strategies against urban dirty bomb attacking.

Based on the bars for L3 and M3, the strategy involving all the three approaches has the best result, which means it reaches the lowest probability of more than 30 casualties. If the state of security check turns from 'yes' to 'no', the risk grows significantly for both L3 and M3, indicating that security check is an important approach to controlling the risk of urban dirty bomb. However, if the state of patrol turns from '>2 times' to '<2 times', or if the state of surveillance turns from '24-h-covering' to 'non-24-h-covering', the change of probability of more than 30 casualties is limited, suggesting that patrol and surveillance are less important than security check in terms of controlling the risk of urban dirty bomb. Furthermore, the results also show that when one and only one approach is used, security check shows the lowest probability of more than 30 casualties, supporting that security check performs as the most effective way of decreasing the risk of urban dirty bomb attacking.

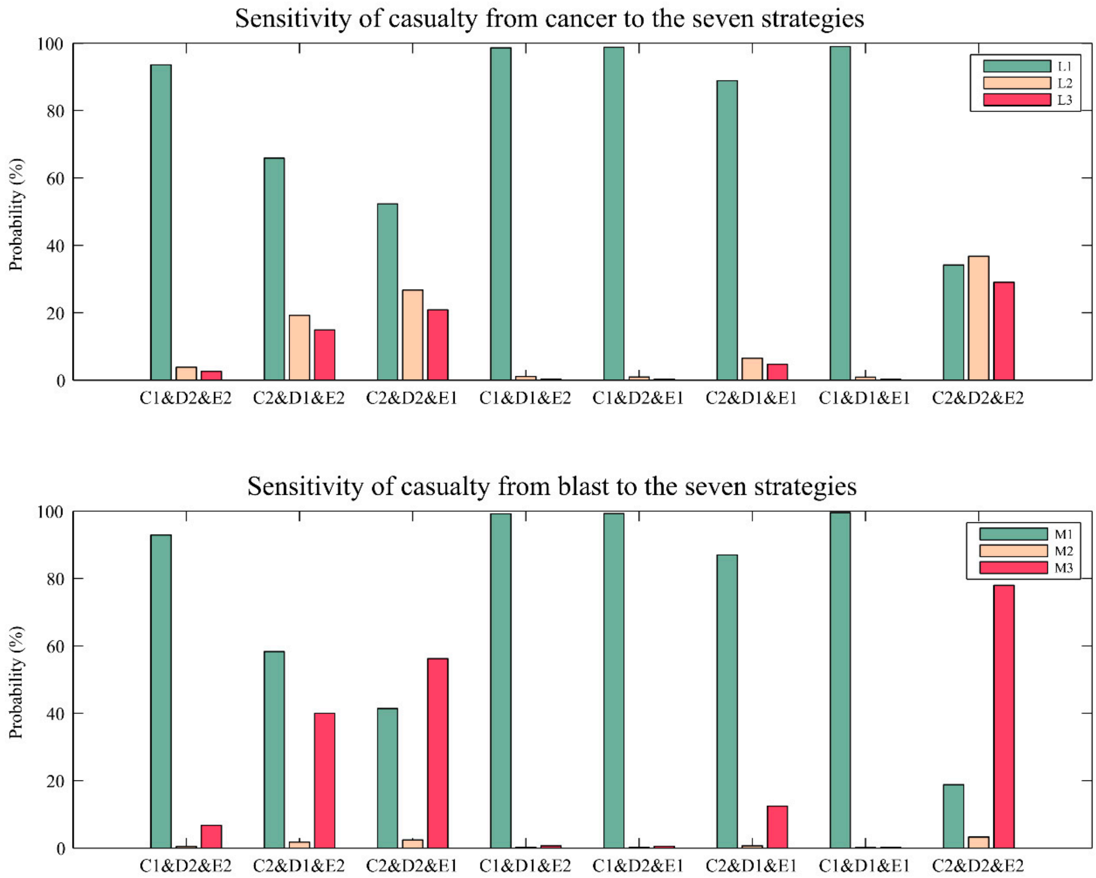

Figure 3. Evaluation of the defense approaches. C1 represents security check = 'yes'; C2 security check = 'no'; D1 surveillance = '24-h-covering'; D2 surveillance = 'not 24-h-covering'; E1 patrol = '>2 times'; while E2 patrol = '<2 times'.

5. Conclusions

This paper takes the TYG area in Beijing as a case study. A Bayesian network of urban dirty bomb attacking is established based on cases studies and expert judgments. The proposed BN model is used to examine how time, location, wind fields, the size of dirty bomb, emergency response and defense approaches affect the risk happening and the casualties from both direct bomb blast and cascading cancers Results show that,

(1) Sensitivity of casualty from cascading cancers to wind fields is less significant;
(2) The impact of emergency response to the direct casualty from bomb blast is not large;
(3) The size of dirty bomb affects casualty from cascading cancers much more significantly than that from bombs explosions.
(4) Whether a bomb is detected by the police is not that related to normal or special time, but significantly depends on its location, indicating that the risk happening of urban dirty bomb attacking is related to its occurrence location. Furthermore, casualty from cascading cancers significantly depends on the bomb location, while casualty from bomb blast is not considerably influenced by the bomb location.
(5) Among the three defense approaches to controlling the risk of urban dirty bomb attacking, security check is more important and more effective compared with patrol and surveillance.

The findings may help the TYG police station as well as the local government make macro-level decisions on urban dirty bomb risk management, and may also provide support for other public security agents on prevention of urban dirty bomb attacking.

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