Determining Premium for Disaster Reinsurance Program through Supply Chain Risk Management: An Application of Peak Over Threshold (POT) Approach

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Abstract— **The purpose of this study is to determine the pricing (premium) for disaster reinsurance program. For those, this study uses the Peak Over Threshold (POT) approach, where the method pays attention to the pattern of heavy tail behaviour on the number of victims killed due to disaster events through extreme values with a reference value called the threshold *u*. The results of the analysis showed that the reinsurance premiums for flood disaster per year that must be paid by insurance company is IDR 712,008,900.50 with the maximum amount of reinsurance risk, *L* is IDR20,000,000,000.00, the insurance company retention, *S* is IDR200,000,000.00, the sensitivity minimum number of victims in one disaster event u with 5 people. The reinsurance premium per year that must be paid by the insurance company to the reinsurance company will increase when the retention insurance company S is smaller, the maximum amount of risk borne by reinsurance L is greater, and the number of victims who die u decreases. This supply chain of information is very useful in disaster risk management.**

Keywords*—Disaster, reinsurance premium, Peak Over Threshold* (*POT) approach, heavy tail behavior, extreme values.*

1. Introduction

Indonesia as a country is placed in the pacific ring of fire and the earthquake-prone area. It makes Indonesia as one of the countries with high potential for disasters, such as landslides, volcanic eruptions, droughts, and floods [1] - [2]. This can lead to huge risks including causing many victims and various kinds of losses. Community and regional government involvement in disaster preparedness can minimize the number of victims and reduce losses [3] - [4]. Another alternative is to initiate an effort to transfer the risk of financing or compensation for the impact of disasters. So that the losses felt by people affected by the disaster can be reduced or borne by other parties, for example, the insurance company. However, insurance companies also have unpredictable risks for losses due to disasters. Therefore, insurance companies require risk management so that if a disaster occurs, the cost of the loss does not result in bankruptcy [5] - [6]. Generally, the way to do is risk sharing, by reinsuring the risks that they might not own to the reinsurance company. Peak Over Threshold (POT) is one method that can be used in calculating disaster reinsurance premiums [7].

Plantinga et al. [8], has examined the catastrophe modeling: deriving the 1-in-200 year mortality shock for a South African insurer's capital requirements under assessment and management. This study examines various types of disasters to assess the risk of death claims faced by insurance companies in South Africa, so insurance companies must share risk with the reinsurance party. In reality, the price of reinsurance premiums is significantly higher and economically unfeasible for insurance companies who buy full protection against destruction. Froot [9], shows that the ratio of disaster reinsurance premiums to losses that are expected to achieve retention is very high while the probability of penetration is low. Seeing the reality of the relatively high price of reinsurance premiums and economic limitations in the purchase of disaster reinsurance, insurance companies are reluctant to share their profits for disaster reinsurance protection. Thus, reinsurance often buys lower reinsurance retention. Ekheden and Hossjer [10], have researched pricing catastrophe risk in life (re) insurance. This study examines the use of Peak Over Threshold (POT) in calculating catastrophic coverage premiums in Swedish cases. This research resulted in a premium price for reinsurance catastrophic coverage. In this study

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also conducted a sensitivity analysis of the influence of several parameters on the expectations and standard deviations of claim costs and premium prices.

Some countries such as Swedish and Africa have adopted the Peak Over Threshold (POT) approach to calculate disaster reinsurance premiums. While in Indonesia this approach is new, and not much has been applied. This situation prompted us to research the calculation of POT reinsurance premiums. The purpose of this study was to analyze the method of calculating the premiums and the magnitude of the benefits of the disaster reinsurance program. This analysis is very important to carry out as a supply chain of risk information in considering reinsurance decisions for disaster management.

2. Methodology

In this section, a brief description of the mathematical models used in this study is discussed.

2.1. Peak Over Threshold Approach

In this sub-section intends to model the problem of the extreme value of financial products using the Peaks Over Threshold (POT) approach, or called the Excesses Over Threshold (EOT) method. This method is done by sorting values that only exceed the threshold, or also called extreme values [7], [10]. This approach usually ignores the timing of events or events and is part of the Extreme Value Theory (EVT) method [11] - [12].

Supposed $X_1, X_2, X_3, ...X_n$ is a random variable from the observation data, which is spread as shown in Figure 1.

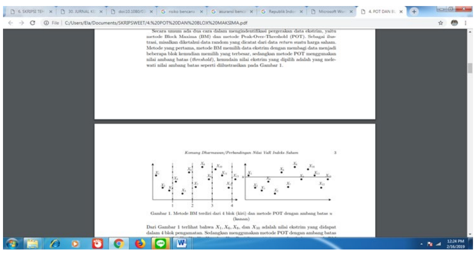

Figure 1. POT approach with the u threshold.

POT approach with the u threshold obtained the value of X_1, X_6, X_8, X_{10} and X_{11} . This approach can be used for limited data due to usage that only requires a threshold as a maximum value [7].

The Determination of the threshold value must be done carefully. Because it will cause a biased estimator and a large variety if inaccuracies occur. Too high a threshold can produce large variations due to a lack of data to infer the model. Too low a threshold can produce biased estimators for extreme data [11].

2.2. Generalized Pareto Distribution

This sub-section discusses Generalized Pareto Distribution (GPD). GPD parameters can be searched by estimating parameters using Maximum Likelihood (MLE) with a threshold u where the higher the threshold value u then the distribution function will approach GPD. This distribution is an appropriate approach to model extreme events with the POT approach [7].

The density function or the probability density function is given as [13]:

$$f_{(\xi,u,\sigma)}(x) = \begin{cases} \dfrac{1}{\sigma}\left(1+\xi\dfrac{(x-u)}{\sigma}\right)^{\left(-1-\frac{1}{\xi}\right)}, & \xi \neq 0 \\ \dfrac{1}{\sigma}\exp\left(-\dfrac{x-\mu}{\sigma}\right), & \xi = 0 \end{cases} . \quad (1)$$

The cumulative distribution function can be obtained by integrating the density function, and the result is:

$$F_{(\xi,u,\sigma)}(x) = \begin{cases} 1-\left(1+\dfrac{\xi(x-u)}{\sigma}\right)^{-\frac{1}{\xi}}, & \xi \neq 0 \\ 1-\exp\left(-\dfrac{(x-u)}{\sigma}\right), & \zeta = 0 \end{cases} , \quad (2)$$

on condition $x \geq u$ for $\xi \geq 0$ and $u \leq x \leq \left(u - \dfrac{\sigma}{\xi}\right)$ for $\xi < 0$.

where σ : scale parameter (σ > 0), ξ : shape parameter or tail index ($\xi \in$ R), and μ : location parameter ($\mu \in$ R).

Based on the shape parameter values, GPD can be divided into three types, namely exponential distribution (if $\xi = 0$), Pareto distribution (if $\xi > 0$), and Pareto distribution type II (if $\xi < 0$). Of the three types of distribution, the Pareto distribution has heavy-tailed. GPD is only focused on the distribution of the number of victims killed in the application of disaster events. This refers to the POT approach which is assumed to have a threshold u , which means that the minimum number of death victims can be insured [13].

2.3. Number of deaths due to catastrophic k -th events

This sub-section discusses the assessment of the number of deaths due to catastrophic k -th events. Maximum Likelihood Estimation (MLE) is one method that is often used in estimating a data distribution parameter and widely used in the development of new tests [14].

The number of victims died was distributed by Discrete Generalized Pareto Distribution (DGPD), $X \sim DGPD(u, \sigma_u, \xi_u)$, the σ_u and ξ_u parameter can be estimated using the MLE method. DGPD distribution form is given as an equation as follows [10]:

$$G_{(\xi, u-\frac{1}{2}, \sigma)}(x) = 1 - \left(1 + \frac{\xi(x - u + \frac{1}{2})}{\sigma}\right)^{-\frac{1}{\xi}}, \quad (3)$$

where X_k : number of death due to catastrophic k -th events, σ : scale parameter (σ >0), ξ : shape parameter or tail index ($\xi \in$ R), μ : location parameter ($\mu \in$ R), and u : minimum number of victims.

Based on the results of the assessment, it was found that the scale parameter is equal to the average value, $\sigma = \bar{x}$ where σ : scale parameter e (σ >0), and $\bar{x}$: mean. As for the shape parameters is obtained as follows:

$$\xi = \frac{n^2 s - \sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} x_i - n \sum_{i=1}^{n} x_i}, \quad (4)$$

where n : number of data above the threshold u , s : standard deviation, and x_i : number of i -th events.

If $\xi \le \frac{1}{2}$ no variance then the Generalized Pareto Distribution (GPD) distribution has a heavy tail, and if $\xi \ge 1$ no expectation then the GPD distribution has a heavy tile [7], [10].

2.4. Number of deaths in a disaster claim

This section discusses the number of deaths in a disaster claim. The number of death borne by k -th disaster, which is used to generate insurance policyholder data, using the following equation:

$$Y_k \sim Betabin(n = X_k, q, d(X_k) = 0.1\log(X_k)), \quad (5)$$

where $n = X_k$: number of deaths due to catastrophic k -th events, and q : insurance company retention.
Equation (5) has a probability function as follows:

$$p(Y = y \mid n, a, b) = \binom{n}{y} \frac{B(y + a, n - y + b)}{B(a, b)}, \quad (6)$$

where $B(a,b)$: beta function. The selection of $\log(X_k)$ in equation (5) is made to get the right degree of association with smaller disaster events, and slow growth towards independence from large disaster events [10], [15].

$$q = \frac{m}{A}, \quad (7)$$

where q : the probability of success of a disaster insurance policy (market penetration), m : number of sold policies, and A : population size.

$$Y_k = \begin{cases} Y_k', & \text{if} \quad Y_k \ge u \\ 0, & \text{if} \quad Y_k < u \end{cases}, \quad (8)$$

where Y_k : number of deaths in a valid disaster claim [10].

2.5. Total claims for disaster k -th events

This sub-chapter discusses determining the overall amount of claims for disaster events. Here's how to calculate the total claims Z_k in the k -th disaster:

$$Z'_k = Y_k \times \text{ the average of insured money} \quad (9)$$

with condition:

$$Z_k = \begin{cases} 0; & \text{if } Z_k < S \\ Z'_k - S; & \text{if } S \le Z_k < S + L \\ L; & \text{if } S + L \ge Z_k \end{cases}, \quad (10)$$

where Z'_k : i -th individual claim of disaster, L : the amount of risk that the reinsurance company must bear, S : insurance company retention value, Z_k : the total claim in the event of the k -th disaster, and Y_k : number of deaths in a valid k -th disaster claim $(X_k \ge u)$. [10], [16].

2.6. Calculation of premium prices

This sub-chapter discusses the determination of premium prices. Determining the price of risk benefits for which the coverage is transferred is one of the premium functions. Disaster reinsurance companies must set rates high enough to cover the burden of payment of benefits and company operations to produce realistic premium rates. Because this is a function that is quite vulnerable in the insurance company. The three factors must be considered in calculating the basic premium for disaster insurance, namely the expected value and the selected loading coefficient [2], [17].

Determination of the price of insurance premiums on disaster insurance is formulated as follows:

$$C = C(T) = \sum_{k=1}^{K} Z_k, \quad (11)$$

$$P = E[C] + \alpha \times STD(C), \quad (12)$$

with $\alpha \in [0.1,\ 0.5]$, then calculate the profit with the formula:

$$p = \alpha \times STD(C), \quad (13)$$

where $E[C]$: expectations of the total price of claims during the 1 year period, $STD(C)$: standard deviation of the cost of claims $C(T)$, $C(T)$: total price of claims on disaster cover during the T period , p : profits received by the reinsurance company, and P : price of disaster insurance premiums per year that the insurance company must pay to the reinsurance company [10], [18].

3. Result and analysis

This section discusses the analyzed data, calculation of market penetration, estimation of GDP parameters, and calculation of premiums and profits.

3.1. Analyzed Data

In research using the POT approach in the form of data on death tolls caused by a disaster. The disasters studied were floods, landslides, and earthquakes for 20 years from 2000 to 2019 in the territory of Indonesia, as well as a simulation study of the sensitivity of insurance company parameters. Data on death tolls over 20 years that exceed threshold values and parameter sensitivity are presented in Table 1.

Table 1. Data on death tolls from disasters throughout Indonesia

Year	Flood			Landslide			Earthquake		
	$u \geq 5$	$u \geq 10$	$u \geq 15$	$u \geq 5$	$u \geq 10$	$u \geq 15$	$u \geq 5$	$u \geq 10$	$u \geq 15$
2000	0	0	0	5	3	3	2	2	2
2001	1	0	0	1	1	0	0	0	0
2002	19	9	6	2	0	0	0	0	0
2003	20	12	4	12	7	2	2	1	1
2004	8	4	1	4	4	3	4	4	4
2005	6	4	4	3	2	2	4	4	4
2006	13	6	6	6	5	3	7	7	6
2007	17	12	8	5	3	0	8	3	3
2008	7	3	0	4	1	1	0	0	0
2009	7	2	1	5	1	0	12	6	6
2010	17	7	5	7	5	2	1	1	1
2011	7	4	0	6	1	0	0	0	0
2012	6	2	0	3	1	0	1	0	0
2013	9	3	2	8	2	1	2	1	1
2014	6	4	2	10	6	2	0	0	0
2015	0	0	0	5	2	0	0	0	0
2016	6	3	3	7	1	1	2	1	1
2017	5	2	1	6	2	1	0	0	0
2018	5	1	1	7	2	1	8	3	3
2019	3	3	3	6	1	0	0	0	0
Total	162	81	47	112	50	22	53	33	32

Furthermore, parameter sensitivity data for all types of disasters is determined as the threshold value u, which is the number of victims killed by disasters that exceed 5, 10 and 15. While the retention of insurance companies S is set at IDR 200,000,000.00; IDR 600,000,000.00 and IDR 1,000,000,000.00. Determination of the maximum amount of risk under reinsurance L is IDR 20,000,000,000.00; IDR 40,000,000,000.00 and IDR 60,000,000,000.00. Determination of the parameter sensitivity value with various conditions, namely u fixed, S fixed, and L fixed aims to determine which conditions cause the highest price of disaster insurance premiums per year, which must be paid by insurance companies to reinsurance companies in Indonesia.

3.2. *Calculation of market penetration*

In this calculation, the total population of Jakarta in 2015 was 10.142,952 people. The number of policyholders is 211,843 people, and the average sum insured is IDR 130,000,000.00 Market penetration calculation is done using equation (7), the result is $q = (211{,}84)/(10{,}142{,}952) = 0.02$.

3.3. *Estimated GPD and Poisson parameters*

The estimated values of the GPD and Poisson parameters for each u re-performed using equation (4) with the help of easyfit software. The calculation results are given in Table 2.

Table 2. Results of estimated GPD and Poisson parameters

Disaster Type	$\hat{\lambda}_{u=5}$	$X_k \sim GPD$		$\hat{\lambda}_{u=10}$	$X_k \sim GPD$		$\hat{\lambda}_{u=15}$	$X_k \sim GPD$	
		$\sigma_{u=5}$	$\xi_{u=5}$		$\sigma_{u=10}$	$\xi_{u=10}$		$\sigma_{u=15}$	$\xi_{u=15}$
Flood	0.24	9.85	0.56	0.12	4.68	0.06	0.07	3.32	0.56
Landslide	0.16	6.48	1.74	0.07	2.25	0.35	0.03	1.92	0.35
Earthquake	0.08	2.5	0.6	0.05	1.6	0.4	0.05	1.7	0.4

From Table 2. the values $\hat{\lambda}_5 = 0.24$ are obtained, then many disaster events are generated from the estimated values so $K_5 \sim Poisson(\hat{\lambda}_5 = 0.24)$. Then, for the number of victims who died in the k-th event of flooding (X_k) the estimated parameters using the GPD distribution were determined and obtained

$$X_k \sim GPD(u - \frac{1}{2} = 4.5,\ \sigma_5 = 0.24,\ \xi_5 = 9.85)$$

From the results of these estimates, data on the death toll will be generated for each incident.

2.7. Calculation of premiums and profits

Furthermore, policyholder data is generated using equation (5), i.e.

$$Y_k' \sim Betabin(n = X_k,\ q = 0.02,\ d(X_k) = 0.1 \times \log(X_k)),$$

then the Y_k value is obtained by referring to the equation (8).

$$Y_k = \begin{cases} Y_k', & \text{if} \quad Y_k \geq 5 \\ 0, & \text{if} \quad Y_k < 5 \end{cases}$$

Continue to calculate the Z_k' value, i.e which is the total amount of the claim in the event of the k-th flood. This is done referring to equation (9), which is $Z_k' = Y_k \times$ the average of insured money. The average sum insured in this study was determined at IDR 130,000,000.00. The Z_k value is obtained by referring equation (10). S is insurance company retention determined at IDR 600,000,000.00, and L is the maximum amount of risk borne by reinsurance companies, determined at IDR 40,000,000,000.00.

Based on the results of the calculation of the previous steps, then calculated $C(T)$ by referring to equation (11). For the death toll of at least u = 5 people, the amount of risk that must be borne by reinsurance companies L is IDR 20,000,000,000.00, and the insurance company retention value is IDR 200,000,000.00. The price of the flood disaster reinsurance coverage premium is calculated by referring to equation (12), and the result is: P = 142,674,900+0.5(1,138,668,001) = 712,008,900.50.

Furthermore, the amount of profit is calculated using equation (13), a value of p = 7,120,089,005-142,674.90 = 5,693,340.01

Using the same method, for some conditions the minimum number of deaths *u*, the amount of risk that reinsurance companies must bear *L*, and the insurance company fixed *S*, the results of calculating the price of premiums and profits appear as given in Table 3.

Table 3. The results of the calculation of premiums and profits for fixed S

Condition	S (Million)	L (Billion)	u	Mean	Stdev	Premi	Profit
S fixed	200	20	5	142,674900	1,138,668,001	7,120,089,00.5	569,334,000.50
	200	40	5	23,082,700	370,164,639	208,165,019.50	185,082,319.50
	200	60	5	33,941,800	574,928,141	321,405,870.50	287,464,070.50
	200	20	10	7,801,600	136,023,719	75,813,459.50	68,011,859.50
	200	40	10	9,641,900	144,102,798	81,693,299.00	72,051,399.00
	200	60	10	12,882,900	152,242,227	89,004,013.50	76,121,113.50
	200	20	15	3,539,400	98,356,868	52,717,834.00	49,178,434.00
	200	40	15	2,613,900	95,250,214	50,239,007.00	47,625,107.00
	200	60	15	4,815,300	178,801,447	94,216,023.50	89,400,723.50

Also using the results of the calculation of the previous steps, the $C(T)$ value is calculated using equation (11). Furthermore, for flood disaster reinsurance with the amount of risk that must be borne by reinsurance companies L fixed, it can also determine the price of reinsurance premiums and profits. For a minimum number of deaths u = 5 people, the amount of risk to be borne by reinsurance companies L is IDR 60,000,000,000.00, and the insurance company retention S is IDR 200,000,000.00. The premium price is calculated using equation (12), the result is:

P = 49,103,000+0.5(539,342,641) = 318,774,320.50

The value of profit is calculated using equation (13), the result is:

p = 318774320.50-49,103,000 = 26,9671,320.50

Also using the same method, for some conditions the minimum number of deaths u, the amount of risk that must be borne by the reinsurance company L fixed, and the retention value S of the insurance company, the results of the calculation of the price of premiums and profits, appear as given in Table 4.

Table 4. The results of the calculation of premiums and profits for fixed L

Condition	S (Million)	L (Billion)	u	Mean	Stdev	Premi	Profit
Fixed L	200	20	5	49,103,000	539,342,641	318,774,320.50	269,671,320.50
	600	20	5	26,741,600	427,421,953	240,452,576.50	213,710,976.50
	1000	20	5	23,882,100	471,134,461	259,449,330.50	235,567,230.50
	200	20	10	4,189,500	87,096,182	47,737,591.00	43,548,091.00
	600	20	10	5,382,400	97,343,066	54,053,933.00	48,671,533.00
	1000	20	10	2,064,300	47,204,576	25,666,588.00	23,602,288.00
	200	20	15	5,181,900	138,200,651	74,282,225.50	69,100,325.50
	600	20	15	3,219,500	119,539,519	62,989,259.50	59,769,759.50
	1000	20	15	2,670,700	79,471,753	42,406,576.50	39,735,876.50

Also using the results of the calculation of the previous steps, the $C(T)$ value is calculated using equation (11). Furthermore, for flood disaster reinsurance the amount of risk that must be borne by reinsurance companies fixed u, also can be determined the price of reinsurance premiums and profits. For the number of death at least = 5 people, it can also determine the price of reinsurance premiums and profits. For a minimum number of deaths u = 5 people, the amount of risk to be borne by reinsurance companies L IDR 20,000,000,000.00, and the insurance company retention S is IDR 2,000,000,000.00. The premium price is calculated using equation (12), the result is:

P = 6,060,000+0.5(180,691,463) = 9,640,5731.50

The premium price is calculated using equation (12), the result is:

p = 96,405,731.50-6,060,000 = 90,345,731.50

Also using the same method, for some conditions the minimum number of deaths u, the amount of risk that must be borne by the reinsurance company L fixed, and the retention value S of the insurance company, the results of the calculation of the price of premiums and profits, appear as given in Table 5.

Tabel 5. The results of the calculation of premiums and profits for fixed u

Kondisi	S (Million)	L (Billion)	u	Mean	Stdev	Premi	Profit
Fixed u	200	20	5	6,060,000	180,691,463	96,405,731.50	90,345,731.50
	200	40	5	15,966,800	415,099,509	223,516,554.50	207,549,754.50
	200	60	5	43,381,300	310,427,897	198,595,248.50	155,213,948.50
	600	20	5	2,638,000	131,188,715	68,232,357.50	65,594,357.50
	600	40	5	7,688,900	296,872,079	156,124,939.50	148,436,039.50
	600	60	5	4,616,700	166,753,582	87,993,491.00	83,376,791.00
	1000	20	5	2,351,300	103,616,619	54,159,609.50	51,808,309.50
	1000	40	5	5,498,900	173,518,069	92,257,934.50	86,759,034.50
	1000	60	5	2,681,300	146,662,049	76,012,324.50	73,331,024.50

Using the same methods also used to determine the premium price of landslides and earthquake reinsurance coverage with fixed u, L or S conditions. Noting the values in Table 3, Table 4, and Table 5, it appears that the price of disaster insurance premiums per year that must be paid by insurance companies to reinsurance companies, will increase when the insurance company S retention gets smaller, the maximum amount of risk borne by reinsurance L is getting bigger, and the more victims died u dwindle.

Disaster management is a series of efforts covering the establishment of disaster risk development policies, disaster prevention, emergency response, and rehabilitation. Insurance can play a role in disaster management by providing mitigation alternatives for large risks which, although the probability of occurrence is small, but have a very large impact. In insurance involvement, the database is a supply chain tool for accurate information needed as a basis for financing policies and strategies, as well as the selection of disaster risk financial instruments to ensure proper and efficient implementation. Accuracy of data and supply chain information will directly impact the efficiency of financing. The database and supply chain of information related to potential disasters (hazard), vulnerability (exposure) and the impact of losses (loss), including insurance claim records (claim history) need to be well managed and updated periodically to be useful for increasing the efficiency of risk financing disaster. In addition, an accurate disaster database will assist the government and the insurance sector in developing disaster risk models that are useful for better disaster risk financing planning, including the determination of reinsurance policies for the insurance sector.

4. Conclusions

The conclusions that can be drawn from the results of this study are: The premium price of disaster insurance per year that must be paid by insurance companies to reinsurance companies in Indonesia is highest for flood disasters worth IDR 712,008,900.50, with the condition that the maximum amount of reinsurance risk L is IDR 20,000,000,000.00, insurance company retention S is IDR 200,000,000.00, and the minimum sensitivity of many victims in one disaster event u to a total of 5 people. Besides, for landslides worth IDR 5,057,893,025.00, with the condition that the maximum amount of reinsurance risk L is IDR 60,000,000,000.00, the insurance company retention S is IDR 200,000,000.00, and the minimum sensitivity of many victims in one disaster event u is 5 people. Meanwhile, for an earthquake of IDR 239,306,395.00, with the condition that the maximum amount of reinsurance risk L is IDR 40,000,000,000.00, the insurance company retention S is IDR 1,000,000,000.00, and the minimum sensitivity of many victims in one disaster event u with 10 people. The price of disaster insurance premiums per year that must be paid by the insurance company to the reinsurance company will increase when the retention insurance company S gets smaller, the maximum amount of risk borne by L reinsurance is getting bigger, and the number of victims will decrease. This analysis is useful as a supply chain of information in making reinsurance decisions

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