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Note:

Prioritization of Different Kinds of Natural Disasters and Low-Probability, High-Consequence Events

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In the history of terrestrial lifeforms, several different kinds of natural disasters can be classified in biological history since the Phanerozoic period. The most serious disasters can be classified as (1) volcanic disasters, (2) asteroid impacts, and (3) climate disasters, in reference to the root cause of low-probability, high-consequence (LPHC) events. However, on a shorter timescale, mankind is more vulnerable to frequent disasters, such as (i) large floods, (ii) epidemics, (iii) earthquakes, (iv) tsunamis, and (v) small-medium scale volcanic eruptions. These are known as high-probability, low-medium-consequence events (HPLC). LPHC occurrences have a very low probability of occurring, but they would have catastrophic consequences. HPLCs occur more frequently, with most of them having decadal frequency. They cause local fatalities, but they are never global in scale. In this study, these events are classified and evaluated based on the potential risk for human civilization. We also discuss how to incorporate different considerations related to prioritizing different disasters, focusing on whether insurance mechanisms can be applied or not.

Keywords: LPHC, HPLC, emergency risks, prioritization, insurance

1. Introduction

In the past, large-scale extinction events and epidemics were frequent. mass extinction events (MEEs) are events characterized by rapid decreases in biodiversity during the Phanerozoic Eon.

According to Raup and Sepcoski, Jr. [1], a new compilation of fossil data on invertebrate and vertebrate families indicates that four mass extinction events for ocean life are statistically distinct, in comparison to other extinction events. Little and Benton [2] state that the early Jurassic mass extinction event took place over a long period of time, and was global in scope. According to Raup and Sepcoski, Jr. [1], five distinct MEEs have been determined as significant events: (a) Oldovician-Silurian (O-S) which occurred in 450–440 Ma, (b) Late-Devonian (L-D) in 375–360 Ma, (c) Permian-Triassic (P-T) in 252 Ma, (d) Triassic-Jurassic (T-J) in 201.3 Ma, and (e) Cretasius-Paleogane (K-Pg or K-T) in 66 Ma.

MEEs can be categorized as low-probability, high-consequence (LPHC) events if they are considered to have occurred in the period of human history. They can be categorized into (1) volcanic disasters, (2) asteroid impacts, and (3) climate disasters, according to the root cause of the above five distinct MEEs (considering that (c) P-T and (d) T-J extinction as (1) volcanic disaster, (e) K-T extinction as (2) asteroid impacts, and (a) O-S and (b) L-D extinction as (3) climate disaster). However, on a shorter timescale, mankind is more vulnerable to earthquake (seismic) and flood disasters, including (i) large floods, (ii) epidemics, (iii) earthquakes, (iv) tsunamis, and (v) small-medium volcanic eruptions. These are considered as high-probability, low-medium-consequence events (HPLC).

We draw **Fig. 1** as a risk management by classifying LPHC, HPLC, and MEE based on the dependence of frequency (x-axis) and severity (y-axis). In general, low frequency and high severity risk will be taken care of by risk transfer, for example, insurance. Low frequency and low severity will be taken care by risk retention. High frequency and high severity will be taken care by risk avoid, and high frequency and low severity will be taken care by risk prevention and mitigation, also private company as an insurance.

LPHC such as volcanic disasters, asteroid impacts, and climate disasters are categorized for all four risk management tools. It's because of that LPHC "are caused by a lot of different reasons and include multifaceted aspects, so they are almost impossible to frame into any well-recognized probabilistic format" (Arangio and Bontempi [3]).

HPLC such as large floods, epidemics, earthquakes, tsunamis, and small-medium scale volcanic eruptions are categorized as risk prevention and mitigation.

MEE such as the rapid decreases in biodiversity during the Phanerozoic Eon will be categorized as above and left of LPHC.

Furthermore, emerging risks are defined: "Risk that was previously unexpected or that was previously expected but found to be far more frequent and serious than previous expectations" by Yoshizawa [4], and we employed some emerging risks that are equal to LPHC in

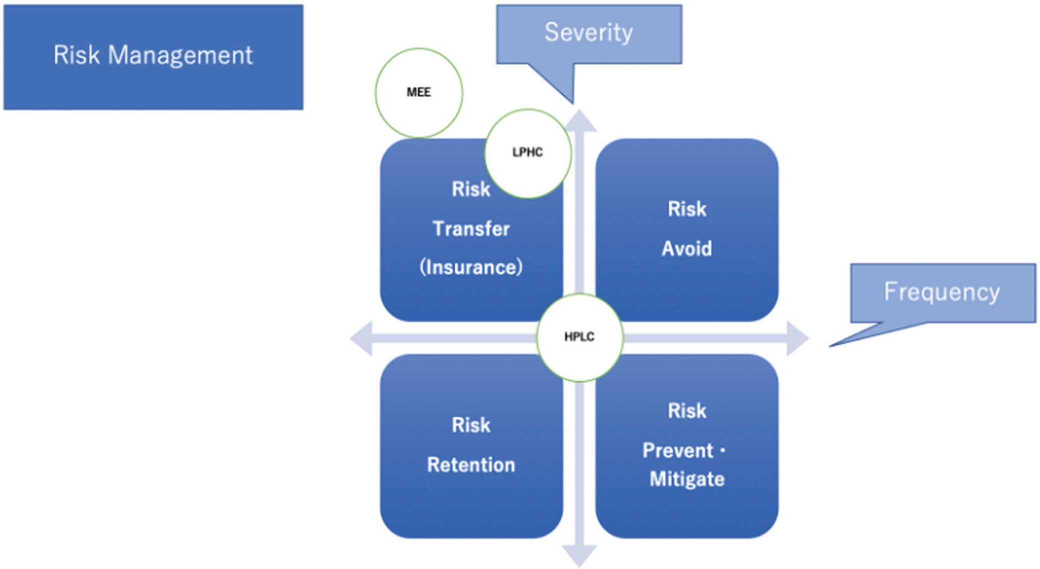

Fig. 1. Risk management classified by frequency and severity.

this paper, for example, volcanic disasters, and climatic disasters.

In the short term, LPHC will be taken care of private company as an insurance, in the long term, it will be supported by government as well in the same manner as earthquake insurance coverage.

Higher concern for mankind when it comes to HPLC rather than LPHC can be caused by (1) the development of civilizations in human history causing a new type of vulnerability that would not have been threat had there been no civilizations with stable settlements. Stable settlements are vulnerable to small-scale perturbations of nature, including floods, earthquakes, and tsunamis, which were not considered serious disasters for a long time when people could freely move away from the affected areas. (2) Small- to medium-scale (up to VEI-6–7) volcanic eruptions happened very frequently and only killed people locally, not globally, such as the VEI-8 volcanic eruption, which occurred relatively recently, only 70,000 years ago in Toba. Another consideration is that throughout history we only recognized small-scale disasters, such as (i) floods, (ii) epidemics, (iii) earthquakes, (iv) tsunamis, and (v) volcanic eruptions.

We have confirmed the largest scale events (v) that took place in the past, but we are not sure about other large-scale disasters. The following is the historical record for each type of disaster.

(i) Flood: The largest flood in recorded history occurred at the very end of the last ice age, around 8,500 years ago, when the black seas were created and large flood events occurred. Of course, it may be the largest ever recorded, but, if the sea levels changed in the past as a consequence of global temperature fluctuation, a "large flood" may have occurred in every glacial and warm period cycle. These large floods may have occurred in every cycle of polar ice melting in the Northern Hemisphere and in Antarctica.

(ii) Epidemic: It is very difficult to tell how large past epidemics have been. The only large epidemic in recorded history was the bubonic plague, or black death. It is difficult to surmise the scale of past epidemics because every piece of organic evidence ceases to exist after a long enough period of time. Epidemics might have occurred repeatedly throughout human history, but homogeneity has increased the risks of different kinds of diseases and extinctions. Keeling and Gilligan [5] state that glandular plague (*Yersinia pestis*) is generally considered to be a historical disease, which still accounts for about 1,000 to 3,000 deaths annually around the world. In this paper, they have extended the analysis of the glandular plague model covering disease dynamics in rats, fleas, and human populations. Sebbane et al. [6] stated: "The plague caused by the gram-negative bacterium *Yersinia pestis* primarily affects rodents, but is also said to be an important human zoonotic disease." He developed a glandular plague model using an inbred Brown Norway strain of *Rattus norvegicus* to characterize the progression and kinetics of infection after intradermal inoculation of *Y. pestis* and the host immune response. Duncan and Scott [7] considered the black death and all European plagues (1347–1670) throughout the 20th century to be epidemic of each plague, but this view is incorrect in the opinion of this review. Evidence is provided that the disease is a viral hemorrhagic fever characterized by a long incubation period of 32 days, which made its wide spread possible, even in a time of limited transport like the Middle Ages [8]. The plague pathogen *Y. pestis*, the causative agent of the plague, it is a highly pathogenic bacterium, but there is no approved vaccine to protect against it, so they propose a vaccine that is easy to handle, which has mucosal effects, and is safe. They have developed a new production and delivery system for the plague vaccine of a tomato-expressed Plasmodium f1-V antigen fusion protein to achieve sexuality, rapid extensibility, and cost.

(iii) Earthquakes: Seismic activity accompanied by strong vibrations may not have been a serious threat throughout human history unless cities and associated structures were built above the affected regions. The biggest earthquake disasters recorded in human history have been the following: (1) the earthquake in Lisbon in 1755, (2) the earthquake in San Francisco in 1906, (3) the earthquakes in the former Tokyo metropolitan zone in 1923, (4) the earthquakes in Mexico City in 1985, and (5) the earthquakes in East Japan in 2011. All of these are associated with the presence of a big city, except (5), which struck coastal cities and nuclear power plants. In the past, there were frequent earthquakes in the Edo area, but all of them are associated with structural damages during the earthquakes. These structural damages never extended beyond one country's border.

(iv) Since March 11, 2011, tsunami disasters have been considered as one of the biggest threats to those living in coastal zones. A tsunami could destroy a coastal city completely or even destroy a nuclear power plant. Tsunamis are recognized as the one of the most horrible disasters for human life. However, it is also recognized that tsunamis can be induced by more than seismic activity under the ocean. They can be caused by volcanic eruptions in the sea, such as the Krakatoa volcano in 2018.

(v) Tsunami Associated with Asteroid Impact: Tsunami disasters can also be caused by asteroids hitting the ocean, as in the case of the Chicxulub impact in 65 Ma. There could have been other tsunami disasters associated with the asteroid impact, which could have killed most of the population of the Earth. The Chicxulub can be classified not only as one of the largest asteroid impacts, but also as a large flood that affected a large portion of life on Earth. Accordingly, if a similar incident happens, it would affect a large population much like a tsunami caused by a collision with a celestial body. Ward and Asphang [9] investigated the generation, propagation, and probabilistic hazard of tsunamis spawned by oceanic asteroid impacts. Chapman and Morrison [10] says that although impacts on the Earth by asteroids and comets (magnitude) are so infrequent as to be beyond our personal experience, the long-term statistical hazards are comparable to that of many other, more familiar natural disasters, raising the question of whether mitigation measures should be considered and assessed as a hazard. Matsui et al. [11] studied the mechanism of tsunami generation by meteorite impact on a shallow ocean at 65 Ma and modeled the propagation of that tsunami in the Gulf of Mexico. They found that the water flow into and out of the crater cavity causes most tsunamis. Gisler et al. [12] state that on a geological time scale, impacts of asteroids and comets with the earth must be considered as a relatively frequent occurrence, causing significant disturbances to biological communities and strongly perturbing the course of evolution.

As for five distinct MEEs, there are three considerable classifications: (1) a volcanic eruption, (2) an asteroid impact, and (3) climate change as described above. As previously stated, the root causes and frequency should be carefully evaluated before considering them as a potential threat for human beings in future generations.

According to Avin et al. [13], we, *Homo sapiens*, are exposed to threats like volcanic super-eruptions.

(1) A volcanic eruption, known as the Siberian Traps Flood Basalt Event, is the MEE that has been the biggest cause for concern since the Cambrian Explosion. According to the hypotheses, the lava equivalent of the size of Siberia was released from inside the earth, causing a significant increase in temperature.

(2) The K-T asteroid impact event is the only historical event that has been confirmed by the existence of a crater. However, considering the number of asteroids crossing the Earth's orbit at any moment in the past, such impacts have probably been more frequent than we realize. There are hypotheses that P-T MEE was caused by an asteroid, just as the other two were. However, finding evidence for asteroid impacts is not an easy task. It should be considered that 70% of the Earth's surface is covered by oceans, and this automatically reduces the possibility of geological proof of an asteroid impact. Oceanic erosion may have accelerated the deformation of an under-water crater. The thick ocean layer may have reduced the deformation of Earth's surface by asteroid impacts unless the location of the impact was in shallow water, as was the case with Chicxulub. However, in such a case, the tsunami impact becomes the first disaster in association with the asteroid. The following table shows the estimated magnitude, in accordance with the size of the asteroid.

(3) Climate change is key in this discussion. Volcanic super-eruption and asteroid impact also cause large scale climate change, first cooling due to the shading effect of a darkened sky by aerosols and then global warming due to the release of GHGs on large scale. For example, after a volcanic eruption, it will be cool for the first three and a half years, and then it will be warm for hundreds of years. This would be the same in the case of an asteroid impact. Other climatological impacts can be caused by different sources, such as solar activity changes, Earth's orbital fluctuations, etc. The root causes of climatic disasters have not been confirmed yet.

Table 1. Classification of different types of disasters and their frequency, affected people, death toll, and economic loss.

	Target	Cause	Frequency	Last disaster (place)	Last disaster (time)	Future Threat	Affected People	Death Toll	Economic Loss	Literature
GRB	Destruction of Ozone Layer - more	Long GRB-Hypernova / Short GRB - Binary neutron star	10 to the 9th power	Global / Ocean Surface	440 MY	??				(Melott et al. 2014)
Super volcanos	Killing locally by lava& Ash	magma chamber	10 to the 4th - 6th power	Toba	74000	Yellowst one	12.5 million (Hoei Eruptions)	13,600 (Hoei Eruptions)	2.5 trillion $(Hoei Eruptions)	Cabinet Office of Japan (2004)
	Killing Globally by gas					Aso (VEI-7)				
						Kikai (VEI-7)				
Asteroid Attack	ELE	NEOs	10 to 8th - 10th power	Chicxulub	65 MY	??	1200	0	$ 30 million	
	Locally		10 to the First-Third power	Tunguska	1908					
Superflare	Modern civilization	Solar activity	10 to the third power	Carrington	1859	Global			$100 million ～	
Climate Change (Natural)	Everything	Solar activity / GHGs / Orbital distance	10 to the Fifth power				60 million	60,000～	$96.2 billion	WHO(2018), Christian Aid(2018)
Climate Change (Anthropogenic)	Everything	GHGs	?		ongoing	Global				
Outbreak of Infectious Diseases	Human		10 to the First - third power		2014 (Ebola)	??	11,315	28,637	$550 million	The World Bank (2015), BBC News(2016)
Terrorism	Human	human	10 to zero-first power		2015	??	10,000 (9.11)	3,043	(Melott et al. 2014)	The Institute for Safer and Securer Society (2007), Yahoo (2018)
Earth quakes	Urban structure	seismic activities	10 to the first power			Kanto, Nankai	468,600	15,897	$16.9 trillion	Asahi (2019)
Tsunami	Coastal structure	seismic activities under the sea	10 to second power			Nankai				
Flood	River	extreme precipitation	10 to zero power			Coming soon	6.9 million (Hurricane Harvey)	82	$160 billion	Masington Post (2017)
AI singularity	Modern civilization	Improvement of AI	?			Coming within 20 years				

Table 1 illustrates the conceptual classification of different kinds of disasters, according to frequency and occurrence, which are basically LPHC.

In this table, we merge many possible disaster types into one. Individually, (i) the γ-ray burst (GRB) is the biggest explosion that has been observed, in terms of energy. There are about 1,000 GRBs per year in other galaxies. If there is ever a GRB in our galaxy, the Milky Way, it will be extremely catastrophic. Even if there were one within 8,000 light years of the Earth, it could have negative effects on our atmosphere. If there were one within 100 light years away, it would destroy the ozone layer. Since a longer GRB may be caused by the explosion of a super massive star, as in the case of Wolf-Reyet 104, it seems long GRBs are infrequent. However, as shorter GRBs may be caused by collisions of binary neutron stars, they may be more common in the Milky Way. There is no evidence that there has ever been a GRB near Earth, but Melott et al. [14] insists that the Oldovisian-Silrian Mass Extinction might have been caused by this type of GRB. We assumed the occurrence ratio (occurrence of GRBs in our galaxy) was once every billion years (Melott et al. [14]), but the ratio might be more frequent if those stars are found to be more common. Costa et al. [15] state that establishing the nature of GRBs is one of the greatest challenges in high-energy astrophysics. The rapid locating of this GRB instigated a multi-wavelength observational campaign that culminated in the identification of a fading optical transient in a position consistent with the X-ray transient reported here. Sari et al. [16] researched the comparison of theoretical models with afterglow observations; we calculate here the broadband spectrum and corresponding light curve of synchrotron radiation from a power-law distribution of electrons in an expanding relativistic shock. They gave explicit relations between the spectral index and the temporal power-law index. Klebesadel et al. [17] did observations of GRBs of cosmic origin and concluded that significant time structure within bursts was observed. Paciesas et al. [18] present tables of the burst occurrence times, locations, peak fluxes, fluences, and durations. In general, results from previous BATSE catalogs are confirmed here with greater statistical significance for [18]. Nousek et al. [19] present new observations of the early X-ray afterglows of the first 27 GRBs well observed by the Swift X-Ray Telescope (XRT).

(ii) Supervolcano (VEI-8) occurred 74,000 years ago in Toba, which caused the Toba Bottleneck theory, an explanation of the reduction in population in regions of India. There is no clear evidence of how violent the Yellowstone supervolcano eruption was, as there is no clear evidence in the fossil record associated with a Yellowstone eruption, but there is some evidence of smaller scale (VEI-7) eruptions, e.g., Tambora, Krakatoa, Aso, and Kikai. VEI-8 eruptions are thought to occur once every 10–100,000 years, but smaller (VEI-7) eruptions might occur every 10 to 100 years. These are very frequent, and they affect many people. (iii) Asteroid collisions such as the Chicxulub event occur every 100 million years, which may be very rare, but smaller scale impacts (with the energy equivalent of the Hiroshima atomic bomb) occur almost annually. Most of these only produce an explosion in the atmosphere, which, in a practical sense, does not have any harmful effects, but once every 100 years, they sometimes occur very close to where people live. Robock et al. [20] have made six climate model simulations of the National Aeronautical Research Community Climate System Model 3.0 (CCSM 3.0) and the National Aeronautics and Space Administration Goddard Space Laboratory Model E. These simulations support the theory that the Toba eruption may indeed have contributed to a genetic bottleneck. Rose and Chesner [21] describe that, as one of the most known eruptions on earth, the 75 ka Toba eruption erupts at least 2,800 km^3 of magma, of which at least 800 km^3 is deposited as a fall of ash. It is said that ash may be widely dispersed. The oldest yearly Tohiwa Tuff (YTT) eruption that occurred in Indonesia 74,000 years ago is one of the largest known volcanic events on earth, but the widespread succession of Central Paleolithic technologies through the YTT event is said to suggest that humanity has survived this major eruption event (Petraglia et al. [22]).

(iii) Asteroid Attacks. The Chicxulub event was only scientifically recognized MEEs occurred 65 million years ago. However, it is considered that there must be other smaller-scale catastrophic events associated with asteroid attacks. Most of asteroids and comets approaching Earth may fall into the ocean without giving clear evidence of the impact. Gusiakov et al. [23] stated that comet fall into the ocean may create Burckle crater around 4800 BC. Smaller-scale asteroid attacks are very frequent, however the big one which may cause mass extinction is generally considered occurring once in every 10 to 100 million years.

(iv) Superflares occur almost every year, but the biggest one recorded was the Carrington Flare, which occurred in 1859. Because human civilizations were not very developed, it did not have a serious impact, but if such a flare occurred in our modern civilization, there would be serious damage in the form of satellite failures, power plant failures, GPS system failures, and other associated damages. Since there is no clear evidence that events such as these have occurred, a group at Kyoto University (Maehara et al. [24]) demonstrated the frequent occurrence of superflares in Sun-like (G type) stars through their observations with the Kepler space telescope. According to their observational results, as Sun-like stars have much more frequent and strong stellar flares, serious concerns about solar activity were raised.

(v) Earthquakes, as the representative HPLC disaster compared with MEE. (v-1) San Francisco Earthquake 1906. Wald et al. [25] studied the source of the 1906 San Francisco earthquake. They then made a more detailed source analysis using Morgan Hill S-body waves as empirical Green's Functions in a finite fault subevent summation, and "moved" the largest 1906 asperity into the Loma Prieta region. Peak ground velocity amplitudes are substantially greater than those recorded during the Loma Prieta earthquake. Aagaard et al. [26] estimated the ground motions produced by the 1906 San Francisco earthquake, making use of the recently developed Song et al.'s [27] source model that combines the available geodetic and seismic observations and recently constructed 3D geologic and seismic velocity models. Borcherdt and Gibbs [28] researched the effects of local geological conditions in the San Francisco Bay region on ground motions and the intensities of the 1906 earthquake. They concluded that the maximum intensity map predicted on the basis of this data delineates areas in the San Francisco Bay region of potentially high intensity for large earthquakes on either the San Andreas fault or the Hayward fault. The map provides a crude form of seismic zonation for the region and may be useful for certain general types of land-use zonation. Kircher et al. [29] presented interim results of an ongoing study of building damage and losses likely to occur due to a repeat of the 1906 San Francisco earthquake, using the HAZUS technology. Song et al. [27] reconciled two previously discordant source models of the 1906 San Francisco earthquake and obtained a model that satisfies both triangulation and seismic data by allowing the rupture velocity to exceed the shear-wave velocity.

(v-2) Great East Japan Earthquake. Tanaka et al. [30] present tsunami-induced coastal and estuarine morphology changes in Miyagi Prefecture, Japan, and the subsequent recovery process in the study area. Furthermore, severe breaching was observed on sandy coasts where a former river mouth was located, due to strong return flow from the catchment area. Yasuda et al. [31] present characteristics of liquefaction in the Tokyo Bay area by the 2011 Great East Japan Earthquake. They state that the reclaimed lands that have been improved by the sand compaction pile method, the gravel drain method, or other methods, have not liquefied. Kato et al. [32] say, "Based on the results of field surveys, coastal dike failures caused by the Great East Japan Earthquake were classified into eight patterns. The results of hydraulic model experiments related to major failure patterns reinforced the proposed failure processes. In addition, the aggregated length of each failure pattern showed that failure from scouring at the landward toe is the dominant failure pattern." Matanle [33] examines whether the Great East Japan Earthquake and tsunami, and the subsequent meltdown at the Fukushima Daiichi nuclear power plant, presents the Japanese state and society with a watershed opportunity to rethink regional revitalization and national energy procurement strategies.

2. Method

2.1. Insurance Mechanisms for LPHC Disasters

In recent years, the necessity for measures against LPHC has increased.

So how much should we prepare for the emerging risks, especially classified as LPHC disasters? Obviously, it is not realistic that human beings will be prepared for a potential GRB scenario and insurance and/or evacuation means. At the same time, asteroid impacts, which were long-time considered as very low frequency risk, are now considered one of the most important emerging risks, at least for NASA. This is because of the statistics and calculation results which took into account the number of asteroids surrounding the orbital path of Earth. Also, for floods and other climate disasters, no one has ever been prepared for them. However, it is an emerging risk which has serious economic effects. Would it be possible then that insurance companies prepare to issue these?

In general, most insurance companies will provide such insurance products for emerging risks at the last moment. This is because most insurance companies will not lose an opportunity if they do not make such efforts. On the other hand, no preparation for these insurance products has ill effects, and it's a lost opportunity for the public to be aware of these potential risks. According to Yoshizawa [4], insurance companies have been trying to commercialize emerging risk insurance, but they have not always responded well to the needs of society.

Risk assessment is an obstacle, especially when insurance companies take on emerging risks. However, the insurance industry has an insurance underwriting method that allows it to undertake risks that are difficult to assess (post-insurance premium adjustment and fileite insurance). Insurance companies are expected to further refine these insurance underwriting methods and actively undertake emerging risks. In addition, the government is required to provide institutional coverage of such insurance underwriting methods (Meiji, the meiji certification standard for insurance).

While the development of insurance products that cover new emerging risks is expected, it should also be taken into consideration that there is an emerging risk that has been covered by existing products.

It can be said that there is a possibility of insuring emerging risk under certain conditions.

We think it is not impossible to build insurance against LPHC if the system described later is built.

According to Yoshizawa [4], Although the insurance industry has been striving to commercialize emerging risk insurance, it cannot always be said that it is fully responding to the needs of society. Regarding emerging risks related to new technologies, the introduction of timely and appropriate insurance products promotes the application and dissemination of new technologies.

In fact, emerging risks are not covered by conventional insurance products. Insurance companies are aggressively working on new insurance product development conducted by screening operations. In addition, profiling and risk assessment will be conducted that lead to the commercialization of insurance (of course, there are many emerging risks that do not result in insurance products, even with the aim of commercializing new insurance). With regard to emerging risks related to new technologies, the introduction of appropriate insurance products in a timely manner promotes the application and dissemination of new technologies.

It is important to note here that even if these efforts by the insurer do not result in the launch of a new product, or even if the insurer did not do any of this, at least in the short term, the insurer will not lose a lot. Rather, instead of embarking on the commercialization of emerging risks, it is better to develop new insurance products that cover the emerging risks when they are transformed into normal risks. Because profiling and risk assessment are possible, it is much easier and safer. However, for individuals and businesses with emerging risks, the inability to prepare a risk transfer method called insurance has to be reluctant to accept emerging risks, and in the context of recent emerging risks it can be said that there is a fear that some technological innovation and its application will be hindered. Therefore, in order to reduce such social losses, it is necessary for insurance companies to give them an incentive to develop new insurance products that cover such risks for emerging risks that were not covered by conventional insurance products. Or, new products that cover emerging risks usually require more time and money to develop products than insurance products that cover risks, and since the diversification of the underwriting risk is also large, it is necessary for society to allow the insurance company to set the premium level to secure excess profit.

Accordingly, in order to establish emerging risks (classified as LPHC events) into insurance products, the risks should be presented to the public so that insurance premiums can be collected. Such kind of issues should be highlighted and discussed at higher attention seeking for higher support from governmental and academic sector. One subject might be the potential risk induced by asteroid impacts. This issue has recently been widely discussed among the public, by the leadership of NASA and other space agencies. Another would be volcanic eruption risk, for this case the potential cost for Mt. Fuji eruption is calculated as roughly 20 billion USD if an eruption similar to the Hoei eruption in 1707 occurs.

Based on **Table 2**, according to National Oceanic and Atmospheric Administration (NOAA) [34], the cost of Hurricane Harvey exceeded $125 billion, Hurricane Katrina was approximately $160 billion, and Hurricane Irma was $50 billion.

According to the Cabinet Office [35], the estimated amount of damage to capital stock during the Great East

Table 2. Estimated economic damages for emerging risks.

	Economic Damage	Source
Flood Tsunami, Earthquake	$160 billion $16.9 trillion	NOAA [34] Cabinet Office of Japan [35]
Terrorism	$6.35 trillion	Institute for Economics and Peace [36]
Ebola	$500 million–$6.2 billion	The World Bank [37]
Climate Change	$100 billion	Cuff [38]
Supervolcano	• $2.5 trillion (Hoei Eruption) • $98.5 trillion (Biggest in Europe)	• Cabinet Office of Japan [39] • Munich RE [40]

Japan earthquake was approximately $16.9 trillion. According to the Institute for Economics and Peace [36], the economic loss caused by Terrorism was $6.35 trillion. According to the World Bank [37], the economic damage of Ebola is estimated to be at least $500 million in sub-Saharan Africa and at most $6.2 billion. According to Cuff [38], the amount of economic damage caused by climate change is estimated to be approximately $100 billion. According to the Mt. Fuji Hazard Map Review Committee [39], the assumed amount of damage caused by the Mt. Fuji eruption in Japan is assumed to be $2.5 trillion, derived from a model of the Hoei eruption. According to Munich RE [40], Etna, the biggest volcano in Europe, likewise caused enormous damage when it erupted in 2001 and again in March, 2002. In 2002, the ash-rain alone caused economic losses of around $98.5 trillion.

As a background, unlike an HPLC, there are no positives to being prepared before a real LPHC disaster. This is because it is low frequency and does not benefit the company. However, the amount of damage and the scale are enormous.

Therefore, in governmental and space-science sectors, such as NASA-JPL, there is a need to communicate the threats and dangers to the public and prepare for these LPHC by creating incentive for the company. The climate change issue is now driven by international organizations such as IPCC for preparatory means. However, from the authors' point of view, they are not yet ready for other types of emerging risks. Finding mechanisms to compensate for those potential risks are essential to increase preparedness for LPHC.

As for the macro framework, we consider an international donor fund for these massive risks as "Prioritization Assessment" (to be explained in a latter section). We did a literature survey and propose new funds which allows us to prepare for these massive risks from many international organizations and governments. First, we should establish the new treaty through an international conference based on the objective target and domain, then we should decide the amount or ratio of a grant from each institution or government. After this, we will have a pilot project to materialize this concept.

As for the micro framework, first we need to decide project objectives, outcomes and each output supporting these outcomes. Since the projects launch, we have co-operated with international organizations, academia, and private companies to develop insurance tools or new social regimes to support this idea. Also we will monitor the results and investigate the issues to resolve these problems.

It is argued that a comprehensive approach based on the Sendai Framework for Disaster Risk Reduction 2015–2020 is necessary in the United Nations Framework Convention on Climate Change. The United Nations has also set out to quantify the damage caused by climate change [41].

According to Japan International Cooperation Agency (JICA) [42], there are methods of risk control (avoidance/prevention, reduction) and risk financing (relocation, possession), but among them, this time, LPHC is a low-frequency but large-scale risk, so the method of reducing the risk itself. It is desirable to use risk financing, which is a method of diversifying risks, instead of risk control, which is a risk control.

Loss insurance, which is a typical mechanism for sharing and distributing all or part of the risk to external parties, is preferable. In risk financing, the loss of society as a whole remains the same, but by dispersing it throughout society, financial risks that an organization cannot tolerate can be avoided.

Based on the characteristics of LPHC in this paper, we propose a new risk financial scheme for large scale disaster risks by referring to Mexico's Natural Disaster Fund (FONDEN) and the Philippine Catastrophe Insurance Facility (PCIF).

FONDEN could be used for rehabilitation and reconstruction. It consists of two complementary budget accounts, the FONDEN program for reconstruction and FOPREDEN program for prevention, and their respective financial accounts (World Bank).

The Philippine Catastrophe Insurance Facility (PCIF) is billed to be the first private sector-focused catastrophe risk financing initiative of its scale that will allow all insurers to pool their catastrophe risks and benefit from efficiencies (ARTEMIS). It aims to allow insurers to manage their catastrophe exposures more efficiently by providing them with part of a more diversified pool instead of a more concentrated risk portfolio (ARTEMIS).

As for funding, it has two sources: Disaster Fund with Trust Funds as Resources from Contributions from

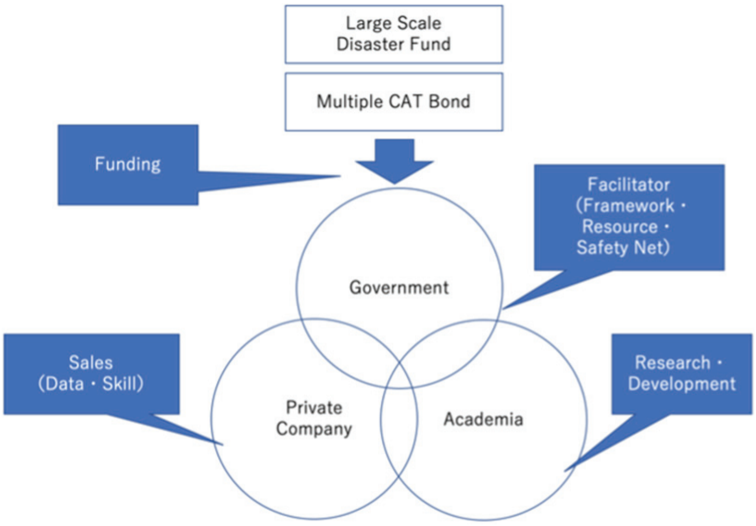

Fig. 2. International schemes for the fund and CAT bond include a government, private company and academia.

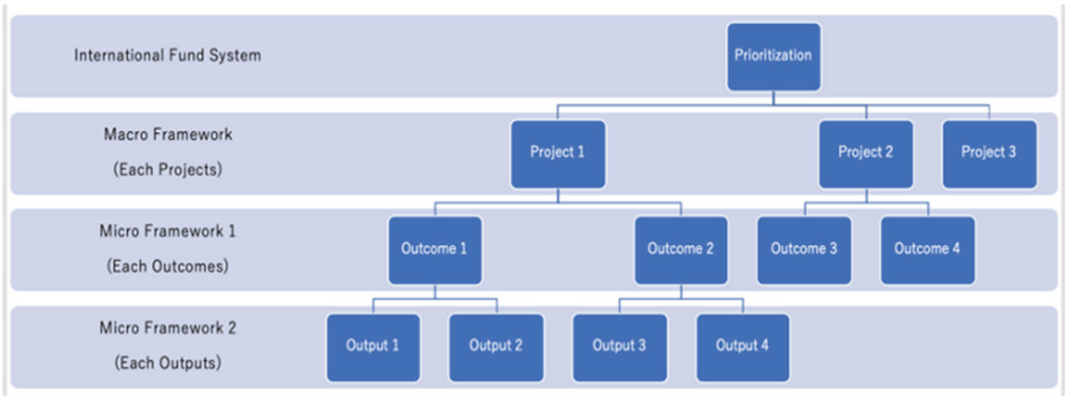

Fig. 3. Macro and micro concepts.

Other Countries and Issuing Multiple CAT Bonds to raise money from market investors. Utilizing these funds, people can work on risk assessment, disaster research, product development, and sales through public-private-sector collaboration.

CAT bonds are bonds with an event-triggered principal loss mechanism in the event of a large-scale disaster, such as a major earthquake, hurricane, or pandemic, under specific conditions. As a response to the risk of loss of principal, a high coupon is set (Nomura Securities [43]). This means that in the event of a disaster that meets certain conditions, such as a typhoon, earthquake, or tsunami, the issuer is exempted from some or all of the principal to be redeemed. In other words, it is a financial derivative (derivative) to receive disaster compensation (Sumitomo Mitsui DS Asset Management [44]).

If the damage exceeds a certain level, which will be set later, we are considering a mechanism to gain access to these funds (as a “Prioritization Assessment”).

The government has established frameworks and laws as facilitators to provide a safety net against more than a certain risk. Private companies sell financial products and insurance based on a huge amount of data and skills, and provide advice to academia. Academia conducts research on disaster risk financing and develops necessary systems and models with the aim of assessing risks and quantifying damage. This is drawn in **Fig. 2**.

The development and implementation of these disaster risk financing schemes for funding and public-private studies is realized separately, and there are several outputs (micros) that support the realization of the outcome (macro), which is the purpose for each project. As a result, it aims to achieve the objective in both macro and micro directions as in **Fig. 3**.

3. Results and Discussion

We propose a prioritization assessment for preparing these LPHC (**Fig. 4**).

Conceptual figures for classifying risk management tools were recompiled based on the frequency (x-axis) and severity (y-axis) by reviewing Clarke and Mahul [45]. LPHC is categorized as the left most position on the graph and it is needed to recognize and assess the risk by preparing “Prioritization Assessment.” Due to the uncertainty

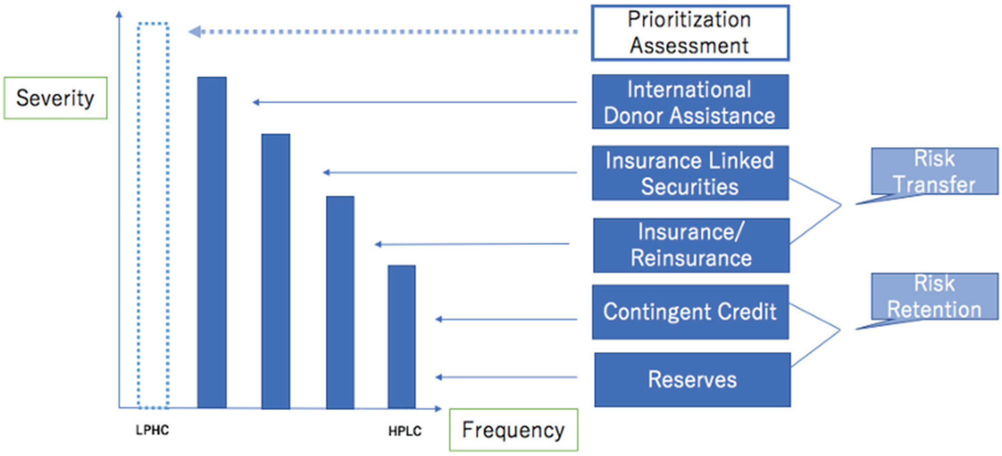

Fig. 4. Risk layering and disaster risk financing strategy for considering LPHC risk (reconstructed figure compiled by Clarke and Mahul [45]).

of the occurrence of severe and catastrophic damage induced by such risks, and due to the extreme potential cost caused by such a disaster, it is very difficult to establish an international donor assistance proposed by Clarke and Mahul [45]. However, it is necessary to prepare research funds, recognize risks, identify them, and evaluate them because they have a large impact and a large amount of damage can occur when considered in the long term.

HPLC is categorized as the right-end position in this x-axis. The larger the potential damage is, the larger framework should be prepared for risk evaluation. At the same time, we should realize that at a certain level of the potential disaster under a lower probability event, the threat itself will be excluded from consideration. In such a case, we propose to include "Prioritization Assessment" in order to compensate such potential hazards.

Basically, HPLC is usually covered by private insurance companies, but for LPHC, the scale and impact are so great that governments and international organizations should cooperate to compensate the three entities for the parts that cannot be covered by the private sector.

It is also important to achieve the following two things. First, the establishment of risk assessment data base. Under the cooperation with each institution, it is better to create a unified database for the entire international community to refer to cases and countermeasures.

It is important to develop the data statistically.

Second, each country needs to clearly sets insurance certification standards. As insurance is a regulated industry, there are many cases where innovative new products are planned but cannot be sold or realized due to regulations. In order to avoid such a situation, it is necessary to establish a system for smooth and speedy approval of insurance.

The public and private sectors will work together internationally to develop a database internationally and collect statistical data. Furthermore, thresholds and insurance standards are set for each country and situation, and thresholds are set for each event like index insurance. In addition, the collected data will be used for insurance and

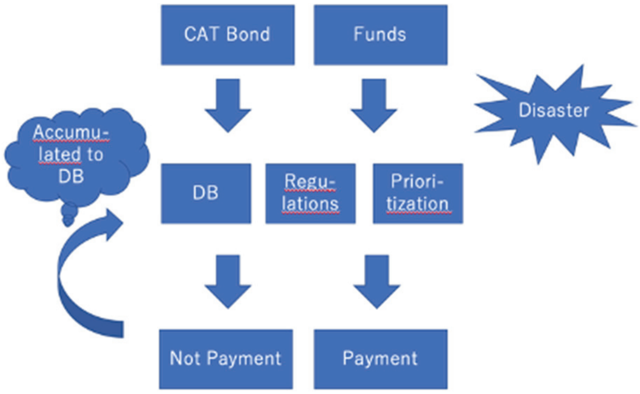

Fig. 5. Industry-government-academia collaboration system as a whole.

development.

In the event of an actual LPHC or emerging risk, payment shall be made from the pooled reserve and compensation shall be made. Then, when some kind of LPHC actually occurs like index insurance, if the threshold value set in advance is exceeded, payment and compensation shall be provided. In addition, we will develop new types of parametric insurance by utilizing the advanced cases and knowledge of each country.

Then, we will accumulate knowledge from case studies and prepare for risk reduction/prevention.

We summarized most of those potential risk management tools (Prioritization Assessment, International Donor Assistance, Insurance Linked Securities, Insurance/Reinsurance, Contingent Credit, and Reserves) depending on the severity and frequency of the risks. As for Prioritization Assessment, it is important to pool the funds in case of unprecedented low frequency and super-massive disasters in the international community, as a whole rather than the private sector and each nation, and to establish guidelines.

The entire process can be summarized in **Fig. 5**.

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