Adaptation Strategies for Risk and Uncertainty:

The Role of an Interdisciplinary Approach including Natural and Human Sciences

OKUMURA Makoto[1]

1. International Research Institute of Disaster Science (IRIDeS), Tohoku University, Japan,

mokmr@m.tohoku.ac.jp

Abstract: The human and social response in Eastern Siberia to the possible changes induced by global warming is the main theme of the RIHN Siberia Project. This presentation explains why we must use an interdisciplinary approach including natural science and human sciences in order to tackle this theme.

The behavior of local society and ordinary people, especially indigenous peoples, is not directly based on the knowledge of modern natural science, but on local empirical knowledge or social norms, which also may have been collected, conceptualized and investigated by human and social scientists. Such empirical knowledge and social rules were not the product of theoretical thinking or optimal design, but of the accumulated pile of tacit knowledge inductively obtained and tested through interactions with other people in the society, other societies, and natural environment in a "trial and error" manner through time. If the effectiveness of such knowledge and rules has been tested only within the range of past environmental change, then we cannot be certain of their effectiveness and applicability in the future, especially in relation to the possible climate changes associated with global warming or to large changes in the social environment, for example in demography. In other words, empirical knowledge can be interpolated, but cannot be extrapolated.

In comparison, natural sciences such as mathematics and physics have a wider range of applicability and extrapability. Even in novel case settings, we can simulate possible situations. When we execute a simulation, however, we must determine the range and step of time and space. At that time, natural scientists usually want to establish consistency and fit with the empirically observed data. As a result, they pay attention only to the interpolation of known phenomena and exclude the possibility of never experienced or unexpected phenomena.

In order to investigate a society's capacity to adapt, we must encourage all scientists to take the risk of extrapolation. Natural scientists need not propose an accurate expectation in a certain setting, but should clarify the range of oscillation of nature and include the possibility that new phenomena will appear. Human and social scientists should investigate whether local knowledge includes any insight into the appearance of new phenomena or not.

1. Risk, uncertainty and ignorance

For the basement of the following discussion in my paper, firstly, I must clarify the concept of "Risk" which is included in both the total theme of the present symposium: "Risk Societies, Edge Environments: Ecosystems and Livelihoods in the Balance" and the session theme: "Global Warming Risk in the Far North". These "Risk" may be used for vague and broad sense, such as , "Something negative problem, which may be happen sometime in the future, but we cannot surely know, when, where, and how strong." In order discuss the role of scientific knowledge on such" risk", we should more carefully define the concept of "Risk".

Frank Knight (1885-1972), worked as a Professor in Economics, Chicago University and one of the world's leading economists, having made significant contributions to many problems of both economic theory and social philosophy, carefully distinguished between economic risk and uncertainty, in his famous book "Risk Uncertainty and Profit (1921)" based on his Ph.D. dissertation at Cornell University. He defined "Risk" as a situation where outcomes are unknown but governing probability distribution is known, and decision making rule such as expected utility maximization can be applied for such situation. In contrast, "uncertain" situation is defined as the situation where outcomes can be listed beforehand but probability cannot measurable. Knight argued that uncertainty gave rise to economic profits that perfect competition could not eliminate. In the line of his discussion, we can also define "perfect unknown" or "ignorance", as the situation where we cannot expect the existence of that outcome until the occurrence of the event.

Risk management is the identification, assessment, and prioritization of risks (defined in ISO 31000 as the effect of uncertainty on objectives, whether positive or negative) followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities. In risk management, risk is captured by the multiplication of impact and probability. It usually dismisses the control of small probability events and uncertainty phenomena, including events of considerable negative impact. Such neglecting is resulted in the poor response after the happening and be blamed from the public, such as the break of sea wall in Taro Town of Miyako City by 3.11 Tsunami, and Fukushima Nuclear Power Plant Problem. Natural science approach usually explains the phenomena through forward analysis along the time passing. If there is any uncertain point in the process, they cannot give reliable probability on the following situations. Natural science also uses an model with parameters, which are sometimes adjusted to fit the measured and observed phenomena. As a result, the model is tuned up to reproduce only "natural" and "ordinal" phenomena and fails to produce "unnatural" and "extra ordinal" situations, even the logic of the model have possibility to do so. Comparing to natural science, human and social science take more flexible approach including reverse analysis, and does not stick to capture phenomena quantitatively. Based

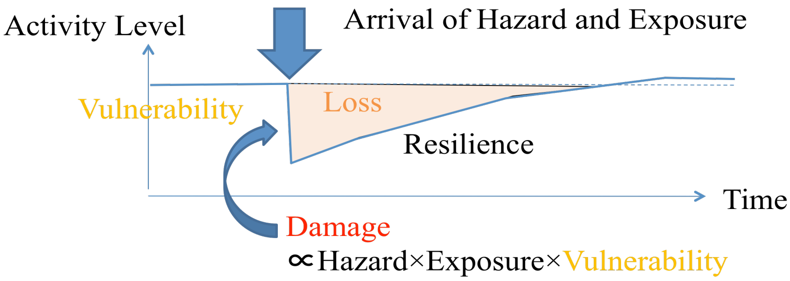

Figure 1 Damage and Loss by Natural Hazard

on the case studies, historical research and inter-regional community comparisons, they can find phenomena which have not been quantitatively captured by natural science.

2. Adaptation concept in disaster management and exceeding hazard problem

(1) Adaptation strategies in disaster management

In the field of disaster management, factors to determine the damage and loss of disaster is conceptualized as Figure 1, showing the time-dependent change of socio-economic activity level. At point in time, natural hazard arrives to the region, and certain amount of socio-economic resource and facilities are exposed to the hazard. If the strength of the social system is not enough to resist the level of hazard, damage will appear just following to the arrival of hazard. Instant damage can be captured by the multiplication of hazard, exposure and vulnerability. Disaster response and recovery activities will be followed, then the level of socio-economical activities will be bouncing back again and at some moment, the activity level reaches to the previous level. That speed is called as resilience by Bruneau (2003). Until that recovery date, certain amount of economic activity was suppressed. He also proposed "Resilience Triangle," capturing the total loss by disaster. Needless to say, resilience can be smaller for the disaster of larger damage, then, it is rather difficult to quantitatively divide resilience from vulnerability.

Based on the concept of hazard, exposure, vulnerability and resilience, we can classify the adaptation strategies in to several groups. Because we cannot directory control natural hazard, there are three ways to reduce the total loss; decrease exposure, decrease vulnerability and increase resilience. The first type strategy decreasing exposure is called as risk aversion and includes land use control avoiding use of risk prone area or temporal pre-disaster evacuation. This type requires large social cost for relocation and life style change. It sometimes violates the traditional way of life such as local hunting, fishery and gathering business. The second type strategy is prevention strategy decreasing the vulnerability. Building a dam, river bank for flood risk are good examples. It usually requires technological cost such as money, material and land for facility buildings, but not require the change of lifestyle. The third type is called as mitigation, increasing resilience. It includes preparation of back-up or spares facilities, buying insurance or other kind of financial system.

Until the Great East Japan Earthquake on 3.11, 2011, Japanese government had been mainly paid attention to disaster prevention, the second one. It included the policy to blockade, isolate and weaken the hazard by physical resisting facilities or building facilities stronger and more durable. When we design such disaster prevention facilities, we must set a certain target hazard level to determine the material, size, location and mechanical strength of the facility. However, that design process cannot certify the performance for the hazard larger than the design target. In other words, we cannot avoid the exceeding-hazard or unexpected hazard problems in any disaster prevention policy.

(2) Vulnerability for exceeding-hazard or unexpected hazard

For simplicity of discussion, here we assume that the exposed facility keeps perfect resistance for the hazard no larger than the designed level and any damage will not be appeared. Let us mind that damage of the fully exposed facility is given as the multiplication of hazard and vulnerability, and vulnerability can be calculated as damage divided by hazard.

Another example was high sea wall overflowed by the great tsunami. Owing to the existence of such high sea wall facility, some of local people had over confidence for safety and did not evacuate promptly. As a result, overflowing tsunami destroyed the sea wall and killed those people who would have evacuated if that high sea wall were not there. We may find that many disaster prevention facilities would be categorized in type 3, for huge exceeding hazard such as 3.11 tsunami.

According to the damage in the area of exceeding hazard, we can classify fragility and vulnerability into 3 types, as shown in figure 2, where damage is plotted for different level of hazard strength. Type 1 facility keeps certain amount of damage reduction for the exceeding hazard too. Dam for cut certain volume of water for flood control is classified in this category. Type 2 facility

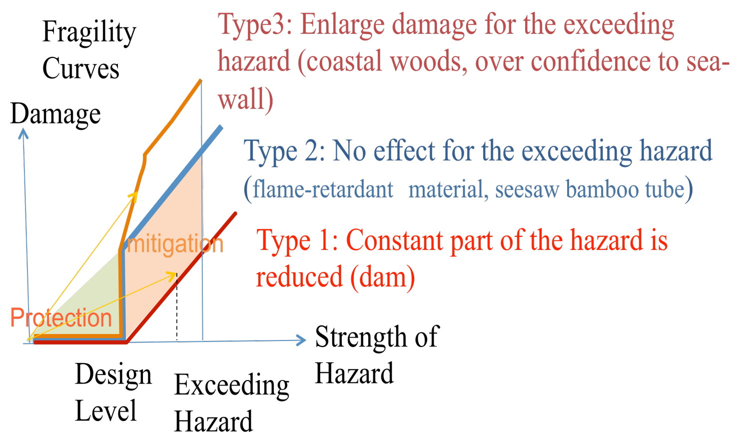

Figure 2 Three Types of Fragility Curves

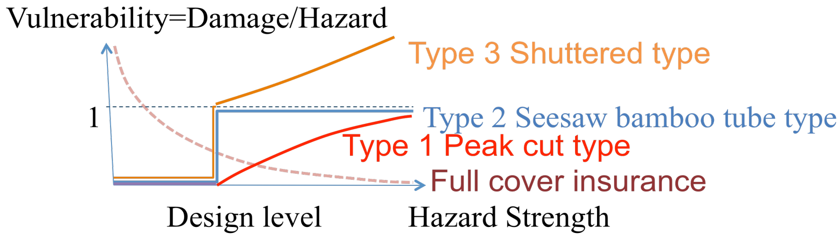

Figure 3 Three Types of Vulnerability

looses the damage reduction effect for the exceeding hazard. This category includes flame retardant material of buildings for fire risk, which does not catch fire for certain heated duration, but once it catch flame it will be burn thoroughly, just as usual building material. Type 3 facilities give enlarged damage for the exceeding hazard. Coastal wood for tsunami hazard is one example: It weaken the strength of tsunami wave to some extent, but by huge tsunami, trees were detached away from the earth and floated and hit to the buildings behind the coast, and made the damage larger there.

Figure 3 shows the vulnerability of facilities categorized in those 3 types, based on that vulnerability is given as damage divided by hazard and the scale of damage is standardized by the amount of damage when the facility were not there. From figure 3, vulnerability for type 2 and 3 suddenly increase once hazard strength exceeds the design level, while vulnerability will gradually increases in type 1 facility. In the same figure, we plot the vulnerability of full cover insurance, which goes gradually down for the exceeding hazard.

(3) Use to the limit and sudden destructions

Type 2 and 3 facilities have possibility of sudden destruction. This feature gives large damage, if many people try to use the facility just to the limit. Unfortunately, such use to the limit is not exception but frequent behavior based on rational decision making. Generally speaking, we feel scarcity value for few supplied goods and service. If a lot of supplier feel risk of destruction and hesitate to supply something using the facility near the limit, risk-taking use may have scarcity value and economic incentive. As a result, risk taking person tries to use the facility just to the limit. However, we cannot perfectly observe the hazard level as well as the actual strength of the present facility, some of them will face to the sudden destruction or collapse.

There are two approaches to avoid the damage of sudden destruction. One is to increase the accuracy of destruction forecasting and monitoring and inform people the limit of usage more correctly. This approach sometimes gives incentive to make a financial support to scientific researches on the natural disaster phenomena, but requires certain sacrifice. The other approach is to build a social system which discourages the use of facility near the limit. To set a more modest limit and prohibit the use over the announced limit is one possible way. But due to the economic incentive for scarcity, violations are easy to occur for such restriction. It is also difficult to determine the limit properly. To burden extra-cost for usage in limit situation seems more effective. Extra charge for facility usage is possible policy option.

3. Possible effect of global warming in far north region

(1) Winter road system in Siberia

Siberia spreads for 2,500 km from the Arctic Ocean to the south border with China and Mongolia, and for about 8,000 km from Ural mountains to the Bering Strait. The density of transport system is very low. In the winter, the temperature falls to -50 °C and the water

Figure 4 Transport network of the Sakha Republic in East Siberia.

transportation becomes impossible because of the freezing of the big river, but the ice of one meter and thicker can support a vehicle. Then *AbtoZimniki*, the winter road in Russian, is settled on the frozen river in winter, as drawn by the broken lines on the map (figure 4).

There is national highway of 22,000 km in the Sakha Republic, and the two third of it is actually the winter road. Around Yakutsk, a winter road is used for about 6 months from early November to late April in the following year. The road paved by asphalt in Sakha is only 623 km, 3 % of the total highway length. In this area, the asphalt becomes soft in the summer, when the temperature exceeds +30 degrees Celsius. Heavy traffic kicks out macadam in the pavement and makes halls and cracks in the pavement. These cracks are widened in winter, by the pressure of freezing water, and new cracks were made. Therefore, the asphalt pavement requires large amount of maintenance cost as well as construction cost. Recently, a vinyl sheet is inserted between the pavement and the roadbed and prevents penetration by water, but it cannot be widely used because of cost problem. The remainder of 6,900 km is unpaved road in earth. It becomes a rough road in summer when the earth layer around 1.5m deep on the permafrost melts to be muddy.

Figure 4 is the transport network map of the Sakha Republic. In the symbol legend of the map, the first orange line is the ordinary road of year-round use, and green line of the second is a winter road. There are several marks of a ship at river harbors, many of them cannot be reachable from the capital city, Yakutsk in winter, unless using the winter roads. Even in the full season road continuously drawn in orange in figure 4, there is no bridge on the point crossing a big river, then they must use ferry service. For example, there are no bridges over the Lena River, the winter road provides much easier crossing transportation. In winter, the snow on the ice surface was removed to make the surface smooth and stimulate the freezing process through cooling from the cold air.

(2) Usage of the Winter Road

As above mentioned, in the Sakha Republic, year around service of the ordinal road transportation is difficult and the winter road system plays a big role. Before the Soviet Union collapses in 1991, necessary living goods and essential foods were lift by helicopters to the settlements and villages under the responsibility of the federal government. Such money- consuming way becomes impossible after the federation collapse, then the existence of small rural villages now strongly depends on the winter road system.

The winter road system around Yakutsk is available for six months, from November to April. But for particular purpose, the season for transportation is limited more shortly. For example, the maintenance of the electric power-transmission wire in rural area must be scheduled in winter, considering the transportation of materials and construction vehicles. Furthermore, they cannot set field work between December and February, when the temperature becomes less than –40 degrees, if considering the risk to the workers' life in case of breakdown of vehicles in rural area. As a result, the electric power company *Sakha Power* plans all maintenance work in the three months; November, March and April.

The winter road systems have been used based on the empirical and local, rather than based on scientific knowledge. Officially, the special commission composed of the specialists from the Department of Transportation, Police, Road construction, Water navigation, as well as Emergency Department, decides the officially permitted dates of use, based on whether the measured thickness of ice is larger than one meter or not. In these years, the official opening date for vehicles under one ton is fixed on December 20th, and for heavier vehicle on January 1st, and two or three days suspension are sometime ordered. However in reality, many vehicles begin to use much earlier than those dates. In the spring, many users are found by early May, after the formal ending date in April, and dropping accidents from the broken ice are frequently occur.

The ice road collapse occurs suddenly and results in serious damage to vehicle, goods and humans. From the typology described in section 2, ice road system especially bridging deep rivers is categorized in type 3 vulnerability, therefore, social system to discourage the use to the limit should be prepared. For example, setting a toll for risky spring season should be implemented.

(3) Global warming in Siberia

Siberia is one of the areas which are strongly influenced in the global warming. For example, the rise of the average temperature from 1975 to 2000 is 0.5 degrees in Celsius in the world average, but 2.5 degrees in Yakutsk. Expectation of the average temperature rise in Siberia in the report of 4th of IPCC reaches 1.5 degrees in 25 years, and century rise becomes 5-6. Winter precipitation is considered to increase, while decreases in summer. Rivers may still freeze up under such climate changes, but the time of the freeze and the melting may strongly change. .

As stated before, there are several works depending on the winter road system, which can be done only the limited time in the severe climate in Siberia. Global warming in the future may change the time of the freezing and melting of the ice on river, then requires the adjustments of work and life schedule of the people. The local empirical knowledge concerning on the winter road will lose the applicability soon. We must provide an alternative knowledge and technology based on more explicit and scientific knowledge.

We have suggested some of the technologies to be developed for the winter road system in the year of global warming. Firstly, the measurement of the thickness of ice is very important technology. The radar measurement technology is promising to give the short term alerting or limiting the passage of heavy vehicles, connected with the mechanical assessment of the strength of ice. Secondly, middle term forecasting of the ice thickness decrease and collapse based on upper stream flow conditions and remote sensing information of upper basins snow thickness and melting. These technologies are too much military-related to be done by the foreign researchers, then Russian

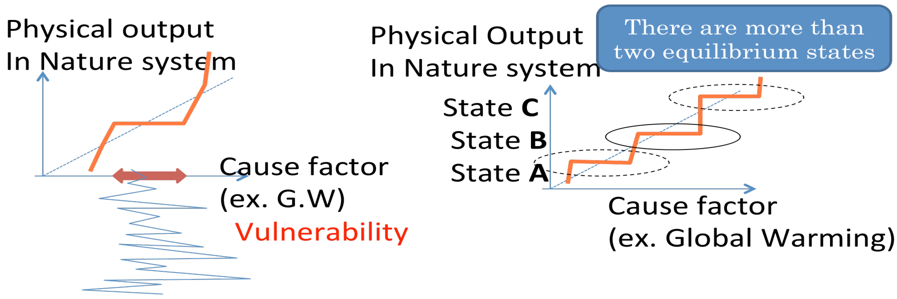

Figure 5 Homeostatis in Eco-system and Several Regimes

researchers should proceed such studies.

However, such kind of research may be "double edged sword", because it stimulates peoples usage to the limit. Social policy to discourage the limit usage should be investigated in parallel.

4. Limit of local knowledge in regime change of natural and eco-system

(1) Homeostatis in ecosystem

From viewpoint of systematic biology, every existing eco-system has internal self-sustaining feedback mechanism to return to the present state after getting external shocks or change of boundary conditions. Needless to say, if external shocks or perturbations are larger and exceed the certain limit, restoring force cannot be expected. As shown in figure 5, system transfers to the different equilibrium. We can call the interval of the state which converges to one equilibrium as a "regime." Due to the larger shock and perturbations, status sometimes transfers into the different regime from the present one.

(2) Limit of local knowledge

Local society and ordinary people especially indigenous ones does not decide their behavior directly based on the knowledge of modern natural science, but the local empirical knowledge or norm of the society, which had been collected, conceptualized and investigated by human and social science. Those empirical knowledge and rules were not the output of theoretical thinking or optimal design, but the accumulated pile of tacit knowledge inductively obtained and tested through interactions with natural environment in "try and error" manors in long history. Those local knowledge and rules had been tested their effectiveness only inside the changes of environments, usually in the present regime. We cannot secure the effectiveness and applicability of the knowledge in the future, after the transition to another regime due to the climate changes occurred by the global warming process or large changes in social environment, such as demographical conditions. In other words, empirical knowledge can be interpolated inside the present regime, but cannot be extrapolated over the edge of regime.

In order to go beyond the edge of the regime, comparative studies seem to be important for human and social scientists. They may provide knowledge about the situation in different regimes.

(3) Beyond “scientific” scientists

Comparing those empirical knowledge, natural science theory such as mathematics and physics have wider range of applicability and more extrapolatable. Even for never experienced case setting, we can simulate the possible situation. However when we execute a simulation, we must determine the range and step of time and space. At that time, natural scientists usually want to seek the consistency and fitting the observed data. As a result, they pay attention only to the interpolation in the experienced phenomena, and exclude the possibility of never experienced or unexpected phenomena.

In order to investigate the adaptation limit of the society, we must encourage all scientists to take risk of extrapolation. Natural scientists need not propose an accurate expectation in certain setting, but should clarify the range of oscillation of the nature and new phenomena, possibly appear.

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