Preliminary Studies on Economic Implications of Improved Ocean Observing Systems in the US and Japan

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Abstract

Ocean observing systems are now being developed as integrated and advanced operational monitoring systems in many parts of the world. Questions about their likely costs and benefits are important to the prioritization and implementation of observing system components.

Under the auspices of the National Oceanographic Partnership Program (NOPP), a US study is underway to estimate the potential economic benefits from improved coastal ocean observing system information. This work focuses on the user sectors of such information, including search & rescue, maritime transport, fishing, spill response, coastal hazards mitigation, and how better information might improve economically important decisions. For the nation as a whole, these initial estimates suggest potential benefits from improved coastal ocean observation and resulting nowcast/forecast products of several hundred million dollars per year.

In Japan, scientists and engineers have initiated a study of a networked monitoring system called ARENA (Advanced Real-time Earth monitoring Network in the Area) to be deployed around Japan. Efforts are underway to estimate the foreseeable cost to set up, maintain, and repair the system, and to compare these costs to its expected contribution to society and the national economy. A first step in this cost/benefit analysis was to review established methodologies and identify useful approaches. Once these approaches were selected, some preliminary examinations were executed. The result shows that the system may bring significant economic value by mitigating or preventing disasters in the wake of heavy earthquakes and/or tsunamis.

1. US Economic Research Into Coastal OOS

Like other nations, the United States are designing and building a large network of instrumentation and data links to continuously monitor biological, physical, and chemical conditions in the ocean and in the ocean-atmosphere interface. This network will extend from the near shore areas of America's ocean and Great Lakes coasts (and those of other countries) to the deep ocean areas.

The expansion of ocean observing systems is made possible by innovations in sensor, computer, and communication technologies that have lowered the cost of instrumentation and made it possible to measure more parameters than ever before. The presence of data distribution technologies such as the Internet have also enhanced the value and cost-effectiveness of such systems, because data can now be delivered directly to potential users at very low or no cost.

While the costs of collecting and distributing data from ocean observing technologies have come down on a per unit basis, the creation of the systems of observing technologies still requires significant investments. Those investments will be made by federal, state, and local governments and by other organization in both the private profit and non-profit sectors. The magnitude of investments required raises questions about what the benefits from such systems will be, and whether these will be sufficient to warrant the required investments.

Over the past two years, a team of US researchers has developed preliminary information about the magnitude of likely benefits that may accrue from current and expected regional observing systems to be deployed in the coastal waters of the United States, including both the oceans and the Great Lakes. These observing systems are being formed as a series of regional systems in areas such as the

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Gulf of Maine, South Atlantic, California, Gulf of Mexico, Pacific Northwest, and Gulf of Alaska. It is anticipated that all of the coastal waters of the United States eventually will be covered by such systems, which will provide nationally consistent measurement of certain parameters (the "national backbone") and also meet particular needs in each region. Output from the network of regional systems will merge with the global observing systems to create a worldwide integrated ocean observing systems (IOOS). For more information about the network of regional observing systems see www.ocean.us.

The information derived from ocean observing systems creates economic value primarily by leading to improved decision making. "Improvement" in this context means reducing the uncertainty associated with actions taken to use marine resources in some way. A large degree of uncertainty surrounds such decisions, much of which exists because the person facing a decision does not have complete information about the relevant state of the ocean at the relevant time. Ocean observing data and the information derived from it reduces this uncertainty, and that reduction in uncertainty is economically valuable. What a decision maker should be willing to pay for this information (the market value of the information) is related to the extent to which it reduces uncertainty, and to the economic resources at stake in the decision.

1.1 The Economic Value of Information

A nowcast or forecast based on ocean observing system data represents information about conditions or phenomena in the ocean. This information has value when it can be used by an individual or an organization to make a better decision – that is, a decision that results in an outcome that is economically superior. The standard economic approach to valuing information requires:

- A description of the information being valued (in this case, typically an improved forecast or nowcast) and of the uncertainty in the phenomena is describes.

- A model of how this information is used to make decisions. Most decisions are made in the face of imperfect information, or uncertainty about how conditions will in fact develop and what the exact outcome will be. Therefore, a basic principle of economic valuation of information is that of "expected values." Expected values are defined as values adjusted for the probability that they will be realized. In the absence of a specific model of decision behavior, it makes sense to assume the decision maker is rational and seeks to maximize benefits. This is described in greater detail below.

- A model of how these decisions affect physical outcomes.

- A model of how physical outcomes can be translated into economic outcomes. The value of a forecast is the difference between the expected value of the outcome of decisions using the forecast, and the expected value of the outcome without the forecast.

A standard Bayesian approach can be used to estimate the value of information contained in a forecast (see Berger 1985). In this model, a decision maker (user of forecasts) must choose among a range of actions represented by *A*. The outcome of each action depends on a state of nature, *S*, which is not known at the time of the decision but becomes manifest later. The manifestation of *S* is modeled as a random variable with probability density function *f(s)*. This probability density function (pdf) describes the probability that the condition (for example, the height of waves at a surfing beach) will lie within a particular range considering only what is known from past observation, and disregarding the new forecast.

Let *B(a,s)* be the consequence (net benefit) to the decision maker of pursuing action *a* if it turns out that *S=s*. The expected net benefit of pursuing action a is then the integral of the product of *B(a,s)* and *f(s)* (see Raiffa 1970):

$$E_o = \int B(a,s) f(s) ds$$

The optimal choice of action without the new forecast (a_0*) is that which produces the maximum expected net benefit (E_0*). If we now provide a useful new forecast to the decision maker, the optimal choice of action and the associated expected net benefit will change. To determine the value of this new forecast, we need to know something about the accuracy of this forecast and something about the frequency with which different conditions arise on average. (For instance, a storm forecast may be more valuable if storms are more frequent than if they only happen once a decade.) How a decision maker revises her estimate of the likelihood of s is described by Bayes' Theorem:

$$f(s \mid x) = l(x \mid s) f(s) / p(x)$$

where *X* is the information in the forecast,
l(x|s) is the probability that *X=x* given *S=s*, and
p(x) is the probability that *X=x*:

$$p(x) = \int l(x \mid s) f(s) ds$$

In simple terms, Bayes' Theorem describes how the decision maker should adjust her prior expectation of the occurrence of event *s* when the forecast says *x*, taking into account how "good" this forecast tends to be.

The new optimal action given forecast X is found be maximizing

$$E\ (a \mid x) = \int B(a,s) f(s \mid x) ds$$

The outcome of the optimal choice, *E*(x)*, now depends on *x*, and the expected value of net benefit is

$$E_X{}^* = \int E^*(x) p(x) dx$$

Since the decision maker could realize expected benefit E_0* without the forecast and E_X* with the forecast, the value of this forecast to the decision maker is E_X* - E_0*.

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1.2 An Illustrative Example: Beach Closures and Beach Use Decisions

Imagine a surfer in Southern California who wants to go to the beach for a day's surfing, but her decision depends on knowing whether the beach is open for swimming and what is the current state of the surf. General weather forecasts are available, as is information about whether the beach is closed or not. (Beach closures usually follow from sewage overflows that may increase the presence of pathogenic bacteria in the water.)

The decision about whether to travel to the beach can be depicted as the interaction between two factors, each of which has two possible outcomes. One is whether the beach is open or closed, and the other, which applies only if the beach is open, is whether the surf conditions are good or bad.

The decision to open or close the beach rests not with the surfer but with public health officials who monitor the presence and location of pathogenic bacteria that could pose a threat to health. The presence of pathogens generally results from overflow of sewage systems from storm events. The location and concentration of the bacteria depends on the location of the sewage outfalls and local tidal and other currents. Based on sampling data and information on currents, the public health official must decide whether to close a beach, post it as potentially hazardous, or take no action (leave the beach open). This decision depends on the information from the sampling regimen and predictions of currents, both of which have elements of uncertainty in them. Because of those elements, the public official faces the probability that the decision to close a beach will be in error. The beach may be safe for swimming, but the official closes it (a false positive outcome, since the data indicates a positive result for pathogenic exposure leading to a close result). Or the beach may actually be unsafe for swimming and kept open in error (a false negative outcome). Since the official is likely to be risk averse, more beaches are likely to be closed when they could be open if uncertainty were reduced.

The decision to open or close the beach is influenced strongly by knowledge of local conditions in the vicinity of sewage outfalls and storm drains. Ocean observing system can provide fine scale (both temporal and spatial) information on physical, chemical, and biological conditions, and thereby significantly alter the public health official's decision problem. By reducing uncertainty, the length of beaches that must be closed can be reduced, as can the risk of false positives or false negatives. A reduction in false positives increases the amount of time beaches are open for recreation, while a reduction in false negatives decreases the risks to swimmers' and surfers' health and safety.

For the surfer, the question of conditions is a subjective one that depends on wind and wave conditions, which may be unique to the particular destination beach. Again, finer temporal and spatial scale oceanographic and meteorological information provides the information the surfer needs to decide whether to make the trip to the beach.

The economic value at stake in these decisions is the value received from safely enjoying the recreational activity. That value is the amount the surfer would be willing to pay for the opportunity to go surfing less the amount that is actually paid (usually transportation costs). If the surfer makes the trip only to find the beach closed or to find surf conditions too large or too small for enjoyable surfing, then there is a loss of value. It is thus the value to the surfer (or other recreationist) that is at stake in this use of the ocean observing system information. The reduction in uncertainty for the public health official creates value to the extent that it increases the value of recreation to those who use the beach.

1.3 Quantifying Economic Value

The information uses outlined in the example of the surfer can be extended to many different types of users. Recreational boaters and those who fish in marine waters have similar needs for fine scale oceanographic and meteorological data to decide when and where to go. Cargo and cruise ships, both sensitive to fuel costs, need real time current information to optimize their routes to and from harbors; and tug/barges and pilot boats are interested in wave height information to avoid hazardous operating conditions. Commercial fishermen have similar needs; and both recreational and commercial fishing success can be improved by knowledge of such parameters as water temperature. Electric generators can optimize fuel generation to minimize costs depending on when the sea breeze sets up on a high demand summer afternoon, while offshore oil and gas operators need information on high velocity loop currents that develop in the Gulf of Mexico and can affect the safety of operations. With accurate surface current information, oil spill response teams can more effectively deploy equipment to where the oil will be and avoid where the oil will not be.

The appropriate measure of economic value in all of these cases is the change in what economists refer to as "social surplus." Social surplus has two components: producer surplus and consumer surplus. Producer surplus in this case is generally a reduction in costs to businesses. Consumer surplus, as in the case of the surfer, is the difference between what one would be willing to pay and what one actually pays for, for example, a recreational experience. "Social surplus" is the sum of producer and consumer surplus. It is the appropriate measurement because it assures that only the value in excess of costs is counted, making it a unique measure that avoid the artificial inflation of values by double counting.

The problem with social surplus and both of its elements is that they can only be measured using exacting, time-consuming, and costly techniques. Other measures of economic activity (broadly termed "economic impacts") such as the value of sales at the wholesale or retail level, or value added (the most common example of which is the Gross Domestic Product), are widely available, but measure social surplus in a rather imperfect manner. Studies of economic values from investments such as ocean observing systems therefore face a dilemma. The most appropriate measure is the least available, while the most available measures are the least appropriate. This is a major reason why estimates of economic benefits at this

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stage of analysis must be considered preliminary and approximate.

1.4 Potential Benefits for US Industries and Recreational Activities

The information needed to develop detailed estimates of the economic benefits of ocean observing systems is, for the most part, unavailable at this time. Both the development of the observing systems themselves and the economic information needed to estimate benefits are presently incomplete. We have therefore attempted to identify likely magnitude of benefits based on the levels of economic activity potentially affected by the information derived from ocean observations, and to explore the methods that can be used to develop detailed estimates for specific applications in selected regions.

The technologies comprising ocean observing systems comprise a wide array of instruments and platforms. They include moored and unmoored buoys, radar, satellite imagery, fixed platforms such as light stations, and platforms of opportunity. Satellites, moored buoys, and radar make up much of the current generation of improvements in ocean observing systems. The data output of these instruments consist of a wide array of parameters, including:

- Wind speed and direction
- Current speed and direction
- Wave height and periodicity
- Air and water temperature at varying heights/depths
- Chemical composition such as salinity
- Biological composition, particularly the density of chlorophyll-A
- Visibility
- Ice (Great Lakes)

In conducting the analysis for this project, no attempt was made to evaluate the benefits of specific technologies, instruments, or platforms, nor was any evaluation of specific communication channels made. The assumption was made that economically-relevant data would be available in an integrated form and timely manner to users irrespective of observation technology or data dissemination means. We made no specific assumptions about improvements in data other than that development of the observing technologies and systems would permit a substantial increase in the amount, quality, and usability of information delivered to users. In some cases, such as the development of methods for more rapid and direct measurement of pathogenic bacteria, we have assumed that such developments will take place and be implemented (we include the use of rapid microbial indicators as one type of instrumentation that could produce data on biological pathogens).

A series of regional case studies have been carried out in the context of the NOPP research project to develop specific models and/or analyses of likely benefits to particular user sectors. Full results of these studies will be released in a final project report in the fall of 2004. Preliminary results of the case studies permit the identification of the order of magnitude of benefits that may be expected on an annual basis from a fully implemented network of regional ocean observing systems. These are shown in Table 1.

Industry/Activity	Order of Magnitude of Possible Annual Benefits (Millions of Dollars/Year)
Recreational Fishing	100s
Recreational Boating	100s
Beach/Shore Recreation	100s
Transportation-Freight	10s
Transportation-Cruise Ships	10s
Seach and Rescue Operations	10s
Oil Spills	10s
Tropical Storm Prediction	10s
Electricity Load Planning	10s to 100s
Ocean Structure (oil&gas)	10s
Commercial Fishing	100s

Table 1 Orders of Magnitude of Possible Economic Benefits from Ocean Observing Systems

The data in this table suggest that annual benefits b users from the deployment of ocean observing systems are likely to run in the multiple $100s of millions of dollars per year. On a discounted present value basis over time, the benefits from a national investment in such systems are likely to exceed the costs (although these costs, along with the specific design of the system, remain to be determined in detail). This finding is consistent with previous conclusions on the economic benefits of such systems.

The data also indicate that ocean observing systems will have the largest benefits where the information from such systems is used by the largest possible groups. Recreation activities are consistently the highest generators of benefits because of the very large number of people who use beaches, boat on the Great Lakes or in the coastal ocean, or engage in marine recreational fishing. Although the per-user benefits are smaller than those realized by others, the large number of users drive the overall magnitude of potential benefits to substantial sums.

Several important caveats must be kept in mind in interpreting these results:

- The fact that the benefits from the systems as a whole will exceed the costs does not mean that the benefits will exceed the costs in every individual case. The configuration of observing systems in each region should take into account the priorities of local and regional user groups.

The estimates presented above assume:

- Full and successful deployment of existing or near-deployment technologies.
- Cost efficient and effective means of communicating the information derived from the ocean observations to users in a timely manner.
- Users are aware of, and effectively incorporate, the information into their decisions regarding their activities
- In the case of commercial fisheries, additional information concerning the state of the marine

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environment is relevant to decisions about managed fisheries and (at some point) will permit increases in allowable catches.

Violation of any of these assumptions may reduce the possible benefits to levels below those estimated here.

2. JAPANESE CASE STUDY: Underwater Cable Network System

2.1. Outline of ARENA Project

In Japan, as mentioned in the abstract, the ARENA plan has been examined. In the ARENA plan, the underwater cable system and other monitoring components, like those under consideration in the United States, is more than a simple system of communication transmitting routes ; it is a kind of high-tech tool for the monitoring system, covering the three dimensional water column and sub-bottom layers.

The concept design of ARENA is shown in Fig.1. A system deployment image is shown Fig.2.

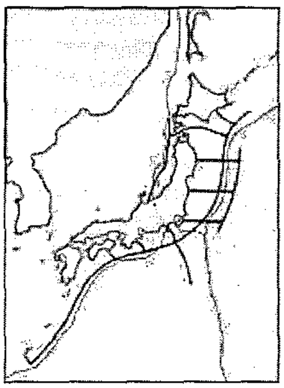


Fig.1 Concept Image of ARENA

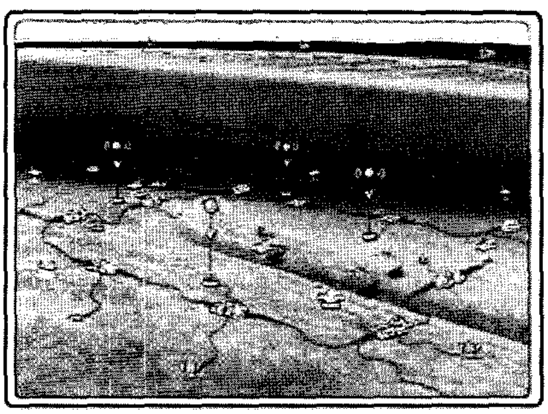


Fig.2. Monitoring tools and devices attached with Underwater Cable Monitoring Network System

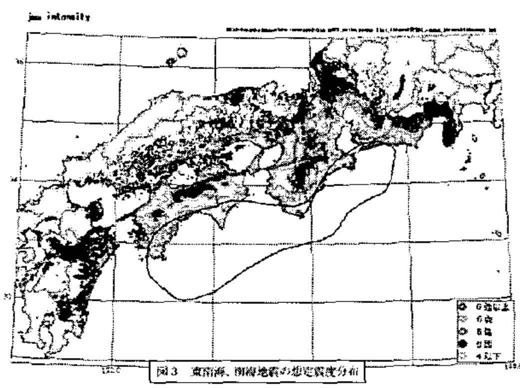
2.2 Anticipated Contribution of ARENA

This comprehensive monitoring network system will provide significant contributions with various real-time and quasi-real-time data for a wide range of fields, including: 1) Earth Science, including earthquake monitoring, earth crust movement monitoring, and Tsunami monitoring; 2) Ocean Physics; 3) Marine Biology; 4) Marine Resource Development; 5) Deep Sea Microbiology; and 6) Ocean Science in general.

Detailed components of ARENA contributions are represented as B1 to Bn in equation (2.2).

2.3 Assumptions of Economic Implication Analysis

The initial study focuses on anti-earthquake disaster effects in the southwest area of Japan. The area shown in Fig. 3 is the most probable area where heavy damages are expected when an earthquake occurs.



(Scale:● >6+, ○>6-, O>5+, ●>5-, O<4)

Fig.3 Hypothetical Earthquake damage map (Source: 14th meeting, Central Anti-disaster Council, Sep. 17, 2003)

For the countermeasure, the underwater cable monitoring system will be examined, and Fig.4 illustrates the idea of deployment.

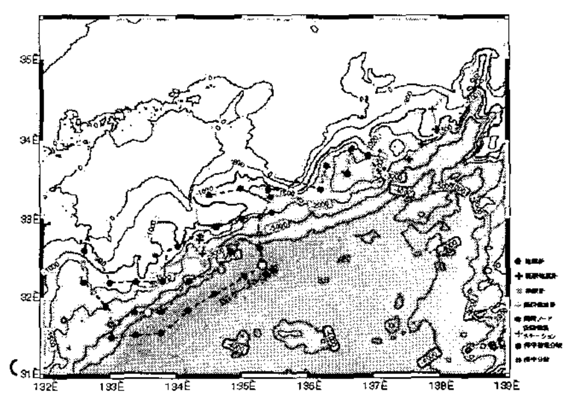


Fig.4 Image of Underwater Cable Monitoring Network System in the hypothetical earthquake area

The estimated cost of this system is as follows.

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Construction-----	13,800 Mio¥	(125.45Mio$)
Maintenance-----	180	(20 yrs)
Repair ------------	200	(twice in 20 yrs)
Total	14,180 Mio¥	(128.90 Mio$)*

*Rate is based upon $1.00=¥110

2.4 Basic Flow and Formula for Economic Implication Analysis

In cost/benefit analysis in general, we have to distinguish between market goods and non-market goods. Market goods can be valued quantitatively using methodologies such as CSM (Consumer's Surplus Method), HPM (Hedonic Price Method), and others. Non-market goods are studied with ESM (Environmental Surrogates Method), CVM (Contingent Valuation Method), Conjoint method, TCM (Travel Cost Method), and others. Of course, I-O Analysis, Macro Economic Model, CGE (Computable General Equilibrium) and others are also some possible alternative methods where they are applicable.

We examined which methodologies are being applied for what kind of public works before entering into the major topic of the study, in order to extract suggestions, if any. The result shows that most of the public works are analysed by a couple of methodologies, based on the specific purposes of the evaluation. The Trunk Road Construction Plan, Flood Control Plan, Railway Construction Plan, Airport Construction Plan, River Environment Improvement Plan, Shoreline Anti-erosion Plan and others were reviewed. Then we recognized that the Logic Model, examination flow in other words, should be used as a basis for the analysis. Fig.5 demonstrates the flow of the analysis.

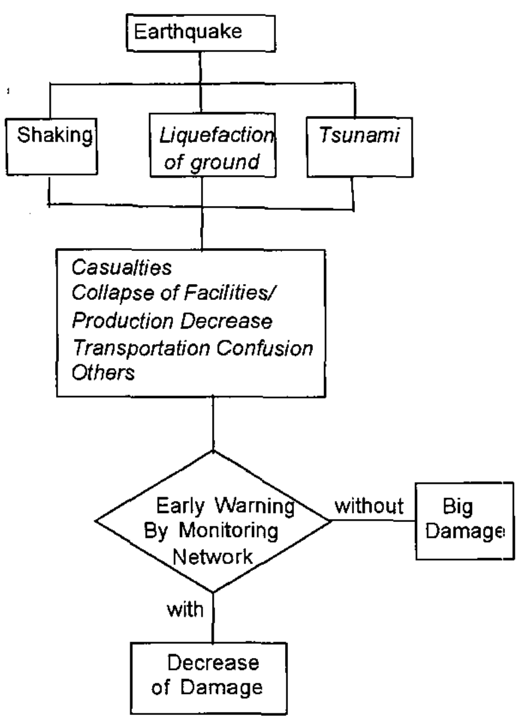

Fig. 5. Flow of the Examination

On the other hand, calculation of the economic advantage will be expressed by the basic formula shown below.

[Total Cost]

$$SC_t=S\ (Ci + Cm + Cr) \qquad (2.1)$$

where C_t = Total Cost
Ci = Initial Cost
Cm = Maintenance Cost
Cr = Repair Cost

[Total benefit]

$$SB_t=S\ (B1(mv+nmv) + B2(mv+nmv) + B3(mv+nmv) + B4(mv+nmv) + B5(mv+nmv) + B6(mv+nmv) + Bn(mv+nmv)\cdots\cdots\cdots) \qquad (2.2)$$

where mv = Market Value
nmv = Non Market Value

B_t = Total Benefit
$B1$ = Benefit for promoting knowledge acquisition on Earth Science
$B2$ = Benefit for promoting Safety and Anti-disaster, and protection of life and property
$B3$ = Benefit for promoting resource and energy development
$B4$ = Benefit for promoting fisheries resource management
$B5$ = Benefit for promoting Science and Research Activities
$B6$ = Benefit for promoting land preservation
Bn = Benefit for others
(Each benefit is independent and no computing interferrence exists)

[Economic Implication]

The break-even point will be estimated by the equation shown below.

$$SB_t/SC_t\ ?\ 1.0 \qquad (2.3)$$

At this time we selected to focus on B2 and B5, but for quantitative analysis will be able to develop estimates for the former benefit only.

2.5 Tentative Estimate of Economic Implication Analysis

In the case of B5, Benefit for promoting Science and Research Activities, further study for quantitative analysis is needed, so this time we have developed estimates for B2, particularly on the earthquake-induced Tsunami.

Taking the following factors into consideration, this kind of monitoring system will provide a great contribution. Examined factors are 1) target area to be protected, 2) time duration that Tsunami reaches the Area, 3) expected casualties due to the Tsunami, 4) average time for evacuation by conventional manner, 5) anticipated time of prediction of Tsunami with the monitoring network, and 6)

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economic value of the human life.

To simplify the analysis, we focused on the decrease of casualties due to the early warning effect of the monitoring network. Since the total cost is estimated as 14,180 Million Yen, the number of lives saved at break-even point is about 450 persons, according to the average of insurance compensation price of human life. 450 persons means only 5.2% of maximum expected casualties in an early morning event (8,600 persons). As about 6,500 citizens were killed by the Hanshin-Awaji Great Earthquake in the Kobe area in 1995, the number of 450 is equal to about 7%.

We also checked the case of transportation confusion if we have a heavy erathquake in this area. The number of Shinkansen (bullet train) passengers is studied in the case of morining, midday, evening and night time; and if earthqauake occurs at 18:00pm, the total number of passengers is estimated as 111,377. Then 450 is equivalent to only 0.4%.

In other words, investment of the total cost of the Underwater Cable Monitoring Network System is very much worthwhile since the cost is equivalent to only a few percentages of the total loss of casualties.

So if we add on the other economic value of the decrease of the Collapse of Facilities, Production Decrease, Transportation Confusion and others, more significance will be brought in. Evaluation methodologies for these items will be different from the casualty decrease effect, and also different with each other.

The benefit for the Promotion of oceanographic research may also be examined by its own methodology, but in this case, it seems difficult to quantify the effects. There are some examples of CBA with respect to R&D activities in general, but an ocean-related analysis might need its own unique perspectives to carry out, pursuing accurate examination.

Remaining tasks include evaluating the other benefits, including B1=Benefit for promoting knowledge acquisition on Earth Science, B3=Benefit for promoting resource and energy development, B4=Benefit for promoting fisheries resource management, and Bn = Benefit for others. So it is natural to say the monitoring network system will be more effective and more significant to the society, and worthwhile to invest.

3. CONCLUSIONS

Established techniques for valuing information are well suited to analyzing potential benefits from improved ocean observing systems. Recent US studies suggest that better coastal ocean observing information can yield economic benefits worth several hundreds of millions of dollars per year from industries and activities such as maritime transport, commercial fishing, recreational boating, fishing, and beach use, energy production and power generation, and search and rescue operations.

Japanese studies suggest that Ocean Observation System will surely bring very high economic value to the society with small amount of investment, comparing to total economic loss without the system.

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