2nd Asia Conference on Earthquake Engineering, March 10-11, 2006, Manila, Philippines

APPLICATION OF A PROTOTYPE MORPHOLOGICAL MODEL FOR EARTHQUAKE DISASTER RISK MANAGEMENT

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ABSTRACT: Disaster risk management (DRM) is a multi-dimensional problem complex. DRM therefore requires a framework which encompasses as much knowledge as possible generated from the field, and wide experience in disaster risk management. It also requires a methodology which can synthesize this knowledge through a participatory dialogue process. Towards this end, seven specialists from the social, natural and engineering sciences collaborated in the initial phase of a facilitated workshop. A second phase ensued with the authors working together to complete a prototype morphological model. The prototype is derived using morphological analysis, which was first developed by Fritz Zwicky, Professor of astronomy at the California Institute of Technology. Morphological analysis enables both researchers and practitioners to structure complex problems, examine thousands of problem configurations and generate innovative solutions. To handle all of the possible configurations, a dedicated software package (MA/Casper) has been developed by the Swedish National Defence Research Agency. This paper illustrates how the prototype can be applied in the case of planning for earthquake disaster risk management. The influence of other hazards, when combined with planning for earthquake disaster risk management, is also examined. Results indicate the wide range of possibilities that can be generated not only from the prototype, but, more importantly, during the actual process of developing it. Future work is required to employ the methodology in a specific location with a team of local experts and practitioners.

KEYWORDS: Morphological analysis, multi-hazard approach, group process, disaster risk management

1. INTRODUCTION

Disaster risk management (DRM) has been defined as “a systematic process that produces a range of measures associated with hazard mitigation, emergency preparedness, impact response and disaster recovery, and which contributes to the safety of communities and the environment; and at the same time parallels risk management and good management practices” (Britton 2005). It also emphasizes pre-disaster, not post-disaster measures, a combination of “top-down” and “bottom-up” approaches, and linking mitigation and development (Mattingly 2002). Both practical experience and expert knowledge possessed by different actors are needed in synergy to achieve the goals of DRM.

The goal of DRM is to reduce loss of lives and property, and damage to the environment and societal cohesion. With this goal in mind, exploring ways and means to combine experience and theoretical knowledge is not easy. It is thus useful to employ tools which can frame as many elements of sound practice and knowledge as possible. The tool should make it possible to validate convictions and to identify uncertainties. Because of the multidisciplinary nature of dealing with disaster risks, it is desirable that such a tool has a broad field of application, accommodating as many ideas as possible and attuned to brainstorming and group process techniques.

This paper discusses the preliminary result of applying a method called morphological analysis (MA) which was first developed by Fritz Zwicky, a professor of astronomy at the California Institute of Technology. As part of the development of the methodological component for the sound practice parameters for disaster risk management in cities in the Crosscutting Capacity Development Program (3cd) of the Earthquake and Megacities Initiative (EMI) (Mattingly, Britton, and Bendimerad 2005), the Earthquake Disaster Mitigation Research Center (EDM) and the Swedish National Defence Research Agency (FOI) cooperated to conduct a two-day “morphological workshop”.

This workshop contributed to the research activities that are an integral part of the “analysis of knowledge and practice component” of 3cd. A knowledge base is being developed in order to help bridge the gap between available knowledge and practice. This knowledge base has been under development in the 3cd Program using various ways of obtaining and distilling information. For the practitioner, a questionnaire survey was undertaken (Fernandez, et al. 2004). During field visits to study cities - Manila and Mumbai, observations and interviews with citizens (lay persons) and participatory workshops (Fernandez, et al. 2005) have been conducted since November 2003.

2. OBJECTIVES, SCOPE AND METHODOLOGY

The objective of this paper is to illustrate the feasibility of using MA to generate a prototype DRM model specifically applied to earthquake disaster risk management. This is a preliminary study aiming at deriving a practical strategy method and/or tool for reducing disaster risk and for assessing sound practice in DRM for cities.

The “Program Definition and Implementation Plan of the 3cd Program” document describes “an interdisciplinary program to address DRM and urban vulnerability reduction issues in complex urban environments” (EMI 2004). It represents a *multi-hazard* or *all-hazard* approach. For the purpose of this paper, however, discussion is limited to earthquakes, in an attempt to illustrate the utility of the methodology employed. The program is “designed as a mechanism for integrating researchers and practitioners, principally from the developing countries." It therefore places importance on the process as well as the product. Disaster research and technology development (DRTD) is often characterized by the primary focus on hazards. If DRTD is to serve the goal of disaster loss reduction, then it must focus not only on hazard science, but on all other sources of knowledge that can build disaster resilience in societies (Fernandez 2005, pp. 58-59). Finding ways to bridge the gap in standards and methods for DRM practice is an area in DRTD that has only recently been given adequate attention.

While taking all the above into account, we recall on-going efforts to develop "systematic methodological frameworks, assessment criteria, and indicators" (UN/ISDR 2004, p. 256) or criteria and standards for disaster/emergency planning (Quarantelli 1998; Alexander 2005). It is not the intention here to compare these different approaches. No single method can be used with total satisfaction. An alternative is to combine at least two methods, with the output of one utilized as input for the other. This has been done by Coyle (2004) in his eight-step ACTIFELD methodology to cope with "strategic problems." For Coyle (p. 1), a strategic problem is "an issue so profound and far-reaching that it affects the very nature and future of an organization." The ACTIFELD tool set "consists of 'soft' methods that do not involve mathematics but, instead, depend on disciplined, imaginative thought." Morphological analysis (MA), one of the methods in the tool set, is utilized to generate possible options. Coyle refers to MA as "a method of technology exploration" since it stimulates innovative thinking to generate such options. These options are not limited to 'hard' technologies but cover all possible ideas and solutions from brainstorming by a group. Actual study groups which FOI has worked with have employed MA together with other structured methodologies assisted by computer, such as the analytical hierarchy process (AHP) and Bayesian Network modeling. Like MA, these structured methodologies are decision analysis tools that allow the use of the knowledge and experience of experts.

In MA, a group of participants are gathered in a workshop setting to deal with a complex problem field. By "complex problem field" we mean a set of issues which are inherently non-quantifiable, contain genuine uncertainties and cannot be causally modeled or simulated. The "subject specialists" in the group consist of practitioners and/or researchers who employ state-of-the-art knowledge and experience from their respective fields of specialization. Also, MA requires skilled facilitation in order get the most out of the knowledge and experience shared (Ritchey 2002). Under ideal conditions, the facilitator may be supported by at least one co-facilitator.

Since disaster risk management is an extremely complex problem area, we would expect it to encompass a wide range of variables and attributes. To develop the prototype model, which deals with these attributes, a software package called MA/Casper, developed at the Institute of Technology Foresight and Assessment by FOI, was employed as a support tool. During the past 10 years, some 80 projects have been carried out utilizing computer-supported MA for risk, threat and strategy analyses. Casper (Computer Aided Scenario and Problem Evaluation Routine) is a PC/Windows program written in C++ and Objective Grid. Although MA/Casper's development platform is not sold openly on the market, FOI provides customers with the required facilitation and a simplified software package, MA/Casper-Viewer, which allows for viewing of data and running the models. The workshop, facilitated by Dr. Tom Ritchey, was held on 22-23 January, 2005, at EDM in Kobe.

The MA workshop was conducted along the following steps (after Ritchey, 2002):

(1) Define important dimensions or variables of the problem complex.
(2) Define a range of values for each variable.
(3) Perform a cross-consistency assessment. Check consistency between all value-pairs of all variables and identify contradictory value-pairs. The relationships between parameter value-pairs is denoted by one of the following "keys" (see Figure 5, "Cross-consistency matrix for disaster risk management in cities"):

"-" = "Yes, these two parameter values can co-exist"
"X" = "No, these two parameter values cannot co-exist"
"K" = "Possible co-existence, but not realistic or not relevant"

(4) Create a solution space by removing all those configurations in the morphological field that contain one or more contradictory value-pairs (MA/Casper performs this);
(5) Examine the solution space by designating one or more parameters as "inputs" or "drivers" (initial conditions), thereby obtaining alternative outputs or solutions. The resultant morphological field becomes a "what-if" inference model.

This type of inference model demonstrates that even a well-formulated problem often has no single solution, i.e., different solution sets are conceivable depending on the set of parameters or factors which are designated in the initial conditions.

3. WORKSHOP SETTING

The following fields of specialization were represented by the seven workshop participants:

- Disaster management theory and practice
- Hazard management

- Integrated disaster risk management
- Land use management
- Public administration and public policy
- Sustainability and development

Four days is regarded as typically required to undertake a modeling effort of this nature. This was shortened to two days and thus a full-scale morphological analysis was not possible. The two-day workshop was conducted as follows. On the first day, the participants introduced themselves by briefly giving a short biographical background pertinent to the subject of DRM. (The workshop program distributed earlier also contained a short profile of each participant.) The facilitator gave a detailed presentation about the procedure, with examples to demonstrate its applicability to the task at hand. The facilitator elicited the main problem which was stated as: How can disaster risk be reduced in cities? Initially, ideas were obtained through brainstorming followed by discussion and group process analysis. The participants brainstormed ideas that relate to the problem; these ideas were clarified, defined, modified, restated, combined, grouped and validated with the end in view of specifying the variables for identifying smart practices in DRM. Using MA/Casper, the variables were entered into the morphological matrix. By the end of the day, the morphological field had eleven parameters (including key "hazard types"), each with a list of possible values or conditions.

On the second day, the group began the task of performing an internal consistency assessment on a selected group of 5 variables pitted against the key hazard types. Each variable value was tested against all other variable values in order to determine whether: (1) the combination will be appropriate for DRM under the circumstances prescribed by the variables; (2) the combination is appropriate under the circumstances given by other conditions; or, (3) the variables are inappropriate for the specific conditions. Because of the time constraint, the group was unable to finish this exercise. The rest of the internal consistency assessment was completed by EDM's team. The material was sent to Tom Ritchey to synthesize the results and compile the model.

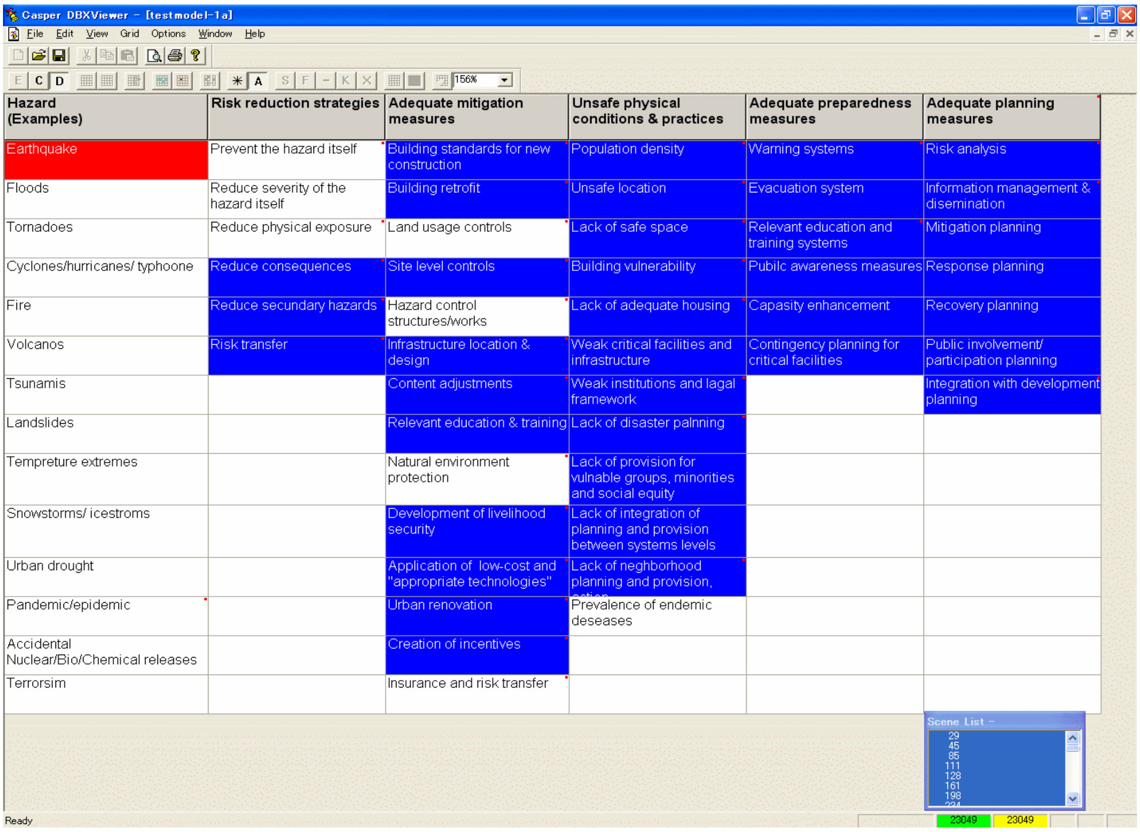
In preparation for the workshop, literature contributed by the specialists was gathered and distributed. Each specialist was requested to contribute at least one paper that best summarizes the issues from the perspective represented, and to bring examples of what might be considered key attributes for 'best/sound practical hazard/disaster/risk management implementation.' The details of the method used can be found in Ritchey and Kaunitz (2005).

4. RESULTS AND DISCUSSION

The prototype model contains six parameters and a total of 67 conditions, distributed as follows.

14 Hazards
6 Risk reduction strategies
14 Adequate mitigation measures
12 Unsafe physical conditions and practices
6 Adequate preparedness measures
7 Adequate planning measures

"Earthquake" is one of the 14 hazards identified. The morphological model focusing on earthquakes is shown in Figure 1. In the case of earthquakes, we see that only three risk reduction strategies (out of 6) are applicable.



Hazard (Examples)	Risk reduction strategies	Adequate mitigation measures	Unsafe physical conditions & practices	Adequate preparedness measures	Adequate planning measures
Earthquake	Prevent the hazard itself	Building standards for new construction	Population density	Warning systems	Risk analysis
Floods	Reduce severity of the hazard itself	Building retrofit	Unsafe location	Evacuation system	Information management & disemination
Tornadoes	Reduce physical exposure	Land usage controls	Lack of safe space	Relevant education and training systems	Mitigation planning
Cyclones/hurricanes/ typhoone	Reduce consequences	Site level controls	Building vulnerability	Pubilc awareness measures	Response planning
Fire	Reduce secundary hazards	Hazard control structures/works	Lack of adequate housing	Capasity enhancement	Recovery planning
Volcanos	Risk transfer	Infrastructure location & design	Weak critical facilities and infrastructure	Contingency planning for critical facilities	Public involvement/ participation planning
Tsunamis		Content adjustments	Weak institutions and lagal framework		Integration with development planning
Landslides		Relevant education & training	Lack of disaster palnning		
Tempreture extremes		Natural environment protection	Lack of provision for vulnable groups, minorities and social equity		
Snowstorms/ icestroms		Development of livelihood security	Lack of integration of planning and provision between systems levels		
Urban drought		Application of low-cost and "appropriate technologies"	Lack of neghborhood planning and provision,		
Pandemic/epidemic		Urban renovation	Prevalence of endemic deseases		
Accidental Nuclear/Bio/Chemical releases		Creation of incentives			
Terrorsim		Insurance and risk transfer			

Figure 1. Morphological field for earthquakes.

The solution space can be described as follows.

- For every parameter, there is a spectrum of values (or conditions) – that represent alternative solutions to the particular issue that the parameter expresses
- The number of formal (non-internally assessed) configurations in the morphological field = 14 x 6 x 14 x 12 x 6 x 7 = 592,704
- After the internal consistency assessment was made, the consistent fields numbered 23,049.

Internal consistency was assessed for logical contradictions and empirical constraints based on current knowledge. Going back to Figure 1, 10 out of 14 mitigation measures, and all preparedness and planning measures are consistent or relevant to deal with the range of unsafe physical conditions and practices, excluding prevalence of endemic diseases.

How the internal consistency check is done is illustrated by the following example: Given a "Risk reduction strategy: prevent the hazard itself", would "Building standards for new construction" be a relevant "Adequate mitigation measure" to take? On the other hand, the question could be asked the other way around, as in: "If we take 'Building new construction' as a mitigation measure, would this be relevant as a risk reduction strategy?"

The facilitator chooses the direction which seems more suitable or logical in order to make the assessment. The assessment is not based on causal reasoning. Instead, pairs are assessed on the basis of whether they "work together" or not. The extreme case is when a relationship is described as absurd or impossible.

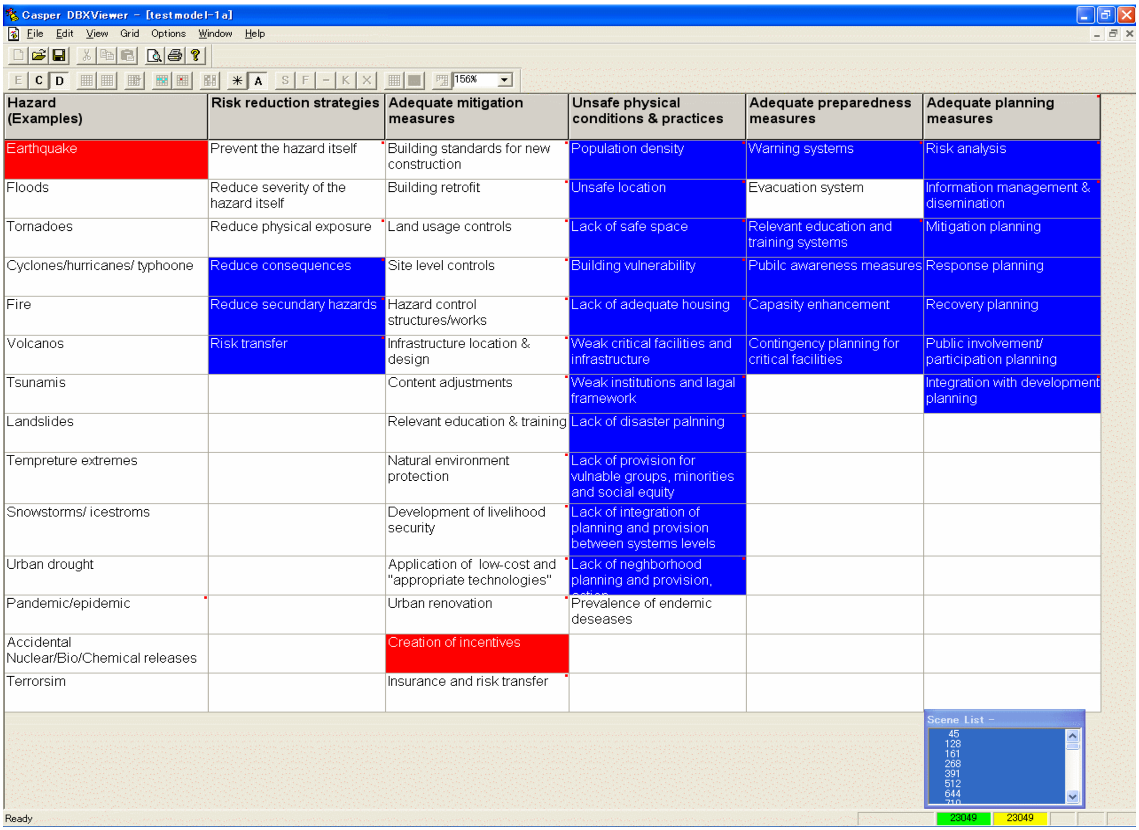


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Figure 2. Field configuration for earthquakes with creation of incentives scenario.

As shown in Figure 2, all three risk reduction strategies are possible with the above configuration. After making a series of trials using mitigation as the driver, it was found that "creation of incentives" is the only "Adequate mitigation measure" that is consistent with all three of the "Risk reduction strategies": "reduce consequences", "secondary hazards", and "transfer risks".

Taking an "all-hazards approach", it is useful to examine which configurations might be applicable to earthquakes combined with other hazards. These combinations might be grouped in terms of: (1) other geological hazards like tsunamis, volcano eruptions and landslides; (2) associated secondary hazards (all of (1) plus fire and accidental releases), and (3) cascading hazards (all of (3) including typhoons, floods, and epidemics).

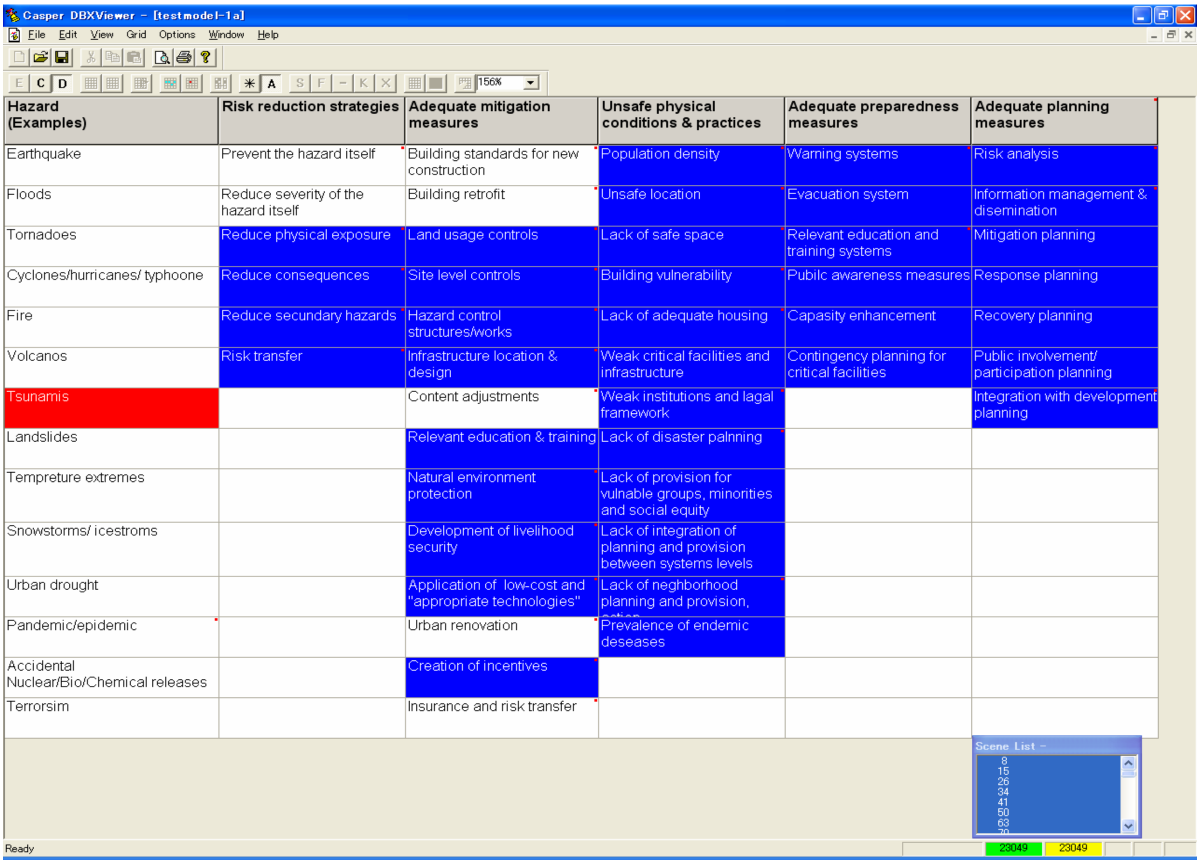

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Figure 3. Morphological fields for tsunamis.

The tsunami is another geological hazard that can result from an earthquake. How does the solution space for tsunamis compare with that of earthquakes? Using the model in this way allows us to compare different "hazard solution spaces", in order determine whether measures for one hazard come into conflict with those for other hazards.

In Figure 3, we find that "land usage control", "hazard control structures" and "natural environmental protection" are useful mitigation measures against tsunamis. This is not the case for earthquakes. While earthquake proofing might be performed, structures to prevent an earthquake from happening or reduce its impact (as a wave breaker does for a tsunami) are not feasible. In the Asian tsunami of December 2005, satellite images of Aceh province showed that the destruction of coastal zones was more severe where mangrove swamps were replaced by fish farms and settlements (Pearson 2005, p. 94). The replanting of mangrove species in coastal areas or the creation of a ‘greenbelt’ can protect the natural environment while it attenuates wave surges (Hiraishi 2003).

The question may arise as to whether it is worth the time and effort to carry out a morphological analysis only to discover the obvious. However, it is necessary to take into account structural safety of tsunami-related structural mitigation measures from the point of view of earthquakes as well. More importantly, the workshop methodology using MA is a highly inclusive process, wherein knowledge is verified from the perspective of several disciplines. Caveats and doubts are laid open. Therefore, the workshop dialogue provides the venue for creating awareness of areas where further research is needed.

Figure 3 indicates that tsunamis and earthquakes do not have the same “compatibility” with respect to land usage control. Here, land usage control means regulating the overall intensity of using a site, type of land use and other aspects pertaining to the same. This illustrates that one is dealing with a multi-objective problem in the case of land use in coastal zones.

In terms of capacity enhancement as a preparedness measure, tsunamis, but not earthquakes, can be dealt with using land usage controls (consistent with the above), hazard control structures, and natural environmental protection. This, in turn, points to structural and non-structural technologies that can be used to reduce tsunami risk. In contemplating structural solutions, it is important to incorporate the hazard control structures in capacity enhancement. Endemic diseases are apt to surface also in the wake of tsunamis. The capacity of communities can be enhanced by incorporating tsunami-related mitigation, which in effect covers more mitigation measures as compared with earthquakes. Had tsunamis not been considered, certain risks would not be dealt with, as efforts would only have been directed towards earthquake risks. Natural environmental protection through the use of man-made mangroves has recently been acknowledged as an appropriate technology for coastal settlements in tropical countries.

The discussions during the workshop were enriched by citing examples, which are illustrative of the issues, as two variable-values are paired. During the cross-consistency assessment, current state-of-the-art measures could be identified and clarified. The broad range of attributes or elements of DRM are shown by the cross-consistency matrix in Figure 5, from which a variety of scenario-strategy configurations can be extracted.

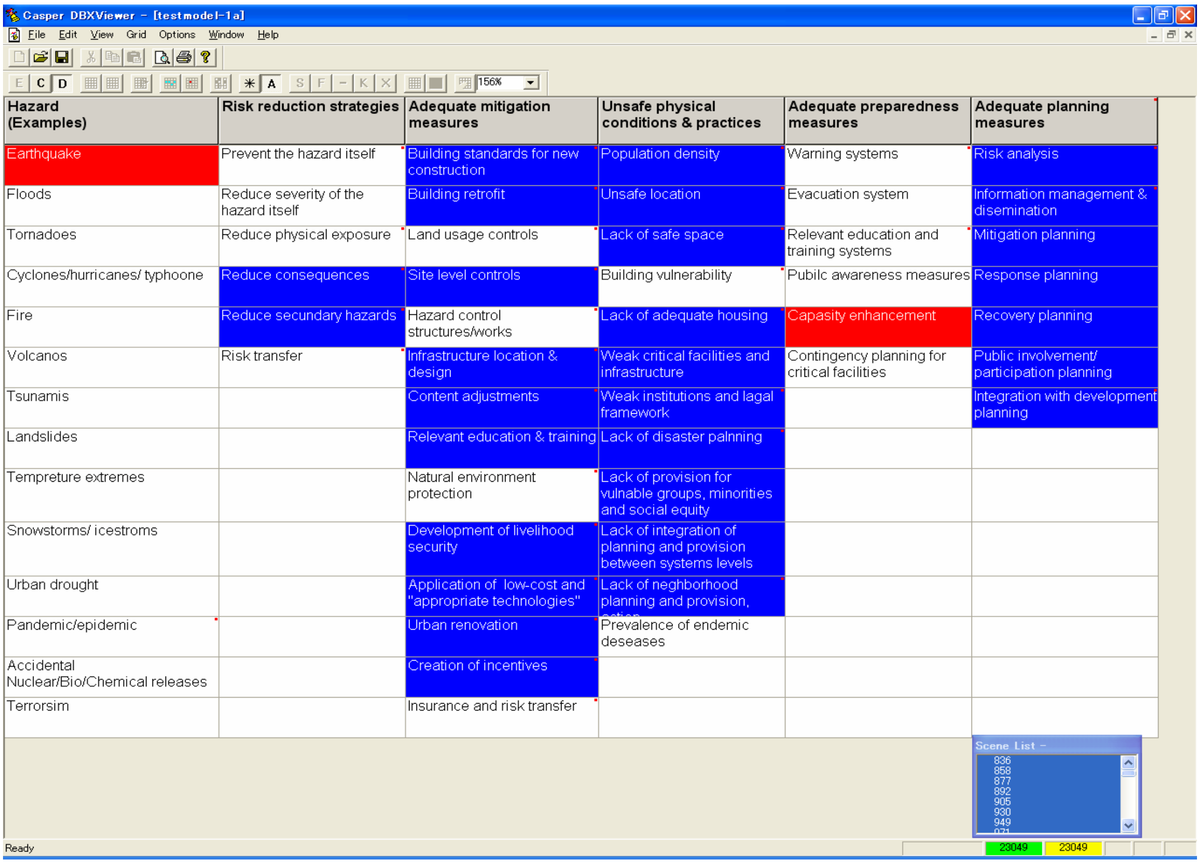

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Figure 4(a). Field configuration for earthquakes with capacity enhancement scenario.

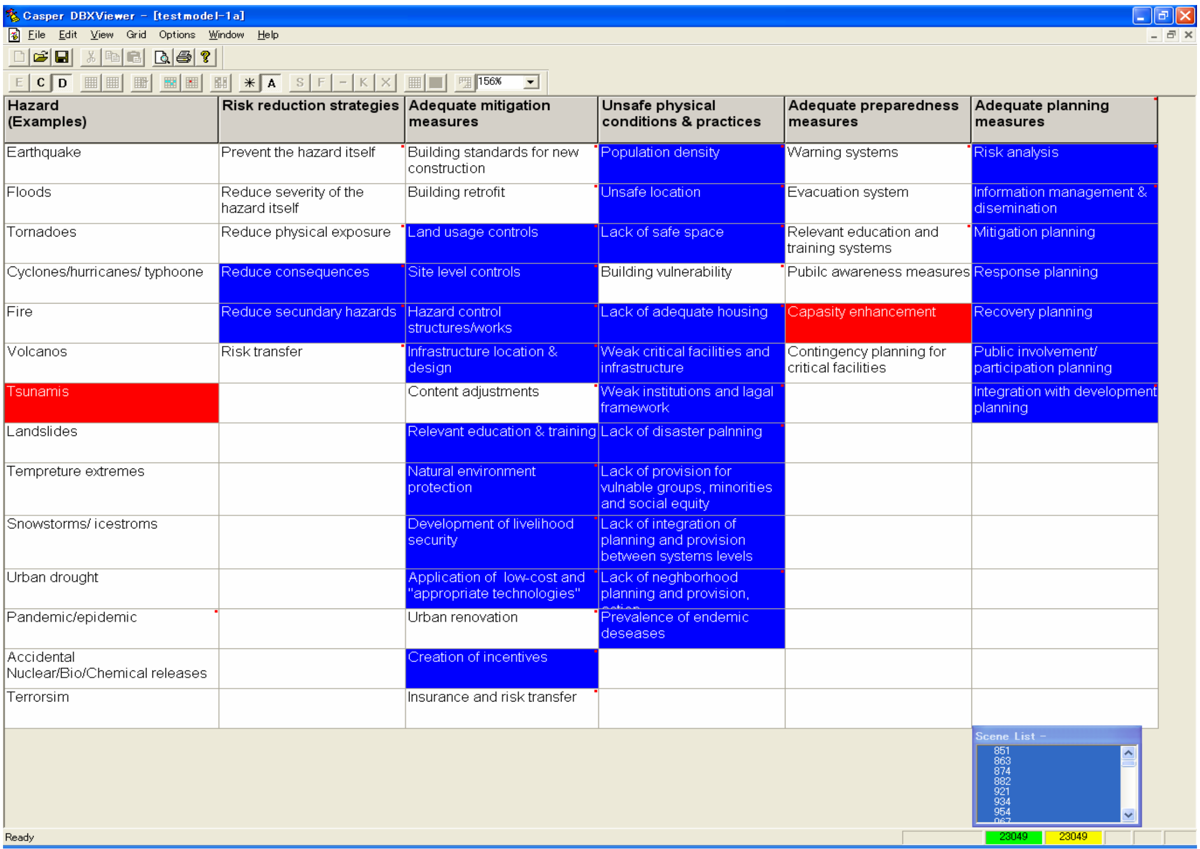

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Figure 4(b). Field configuration for tsunamis with capacity enhancement scenario.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

Formally, the prototype morphological model performs well. However, the current model is not yet fully developed; its content needs to be expanded and refined. For example, there are other parameters that have not been integrated into the model. It is important to understand the method's potential more fully, i.e. in terms of how to apply it in a real cases. Completing the work will help validate the prototype. Completion entails combining MA with other operations research and/or decision analysis methods, as initially proposed.

The workshop was a remarkable success, not the least for permitting cross-fertilization of ideas and knowledge between hard and soft sciences, and between theory and practice. Using the methodology described, specialists developed shared concepts and a "common working interface," shared definitions of parameters and conditions, and shared state-of-the-art knowledge from different fields. In the process, they identified areas where further research is needed. As a proof of this, the specialists concluded that the method has considerable value for DRM, and that the main advantage of the method lies in enabling practitioners and researchers to structure their thinking in DRM and to deal with disaster risks more holistically.

It remains to be seen how the methodology can be shaped for assessing sound practice for megacities. Selecting members of a workshop study group is not an easy task. One criterion is that members share an integrated thinking on DRM for a spatio-socio-economic-institutional complex system like a megacity. The group members therefore recognize and operate on the principle of linking relief and development planning, or disasters and development.

Further work will aim to develop products such as guidelines and diagnostic tools. As suggested by Ian Davis (2005), the team might produce a tool for city and town managers "as they seek to manage their own risks in urban centres of megacities," similar to a tool developed by a UK-based non-governmental organization called Tearfund (LaTrobe and Davis 2005). Intended mainly for development agencies, the tool works with four "attainment levels" using performance targets and indicators to help integrate and expand disaster risk reduction into development planning and programming.

To summarize:

- As a method, MA has considerable value for disaster risk management
- Advantage: enables practitioners and researchers to structure their thinking and create a common terminology and modeling framework
- The exercise needs to be completed to fully understand the method's potential and to validate the prototype.

- Integrated thinking about disaster risk management is essential for the success of any group that would utilize the method in an actual megacity setting.

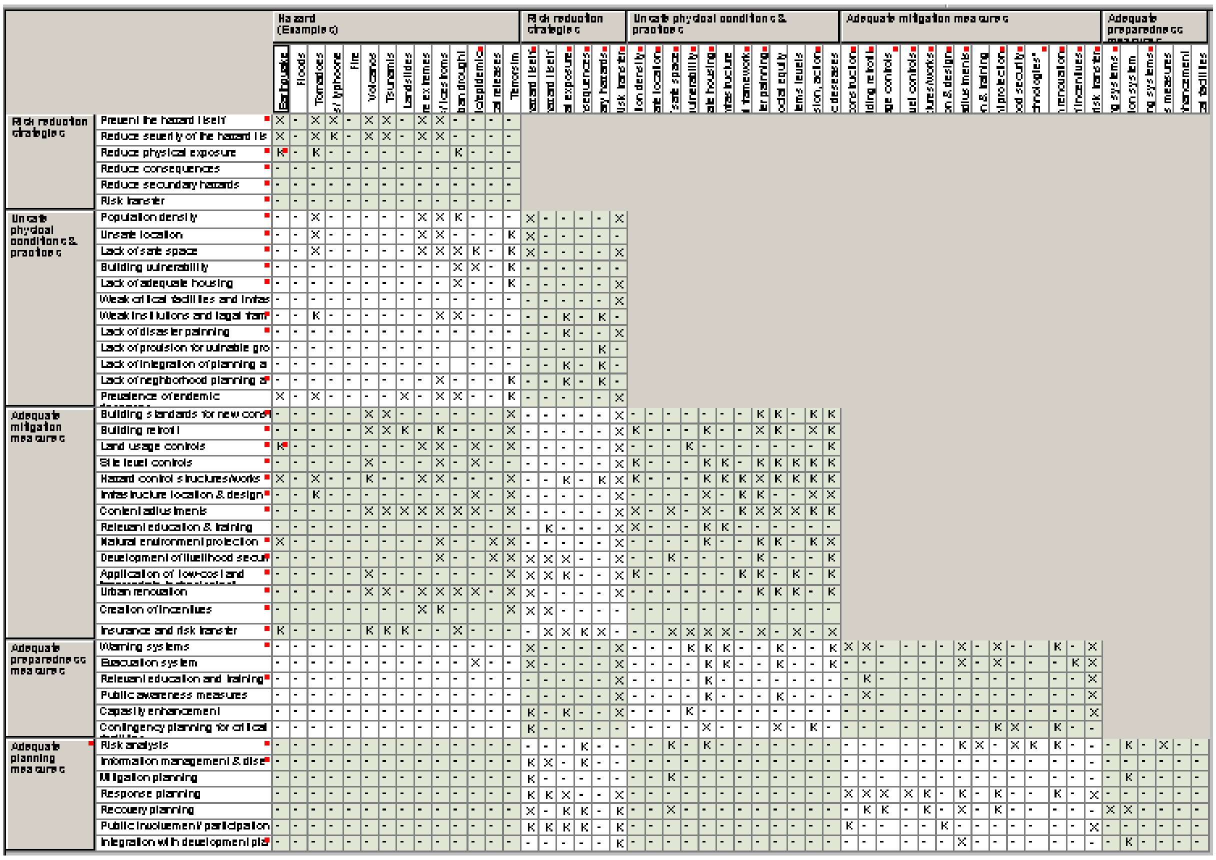

Figure 5. Cross-consistency matrix: disaster risk management in cities.

REFERENCES

Britton, Neil (2005) Developing a framework for identifying sound practices in megacities. 1st International Conference on Urban Disaster Research, 18-20 January 2005, Kobe, Japan (available at: http://www.edm.bosai.go.jp/team4/3cd/index).

Alexander, David (2005) Towards the development of a standard in emergency planning. **Disaster Prevention and Management**, Vol. 14, 2, 158-175.

Coyle, Geoff (2004) **Practical Strategy – Structured Tools and Techniques.** Prentice-Hall, Essex, England.

Davis, Ian (2005) E-mail communication to N. Britton, et al., February 2.

EMI (Earthquake and Megacities Initiative) (2004) **The Cross-Cutting Capacity Development Program: Program Definition and Implementation Plan.** (available at: http://www-megacities.physik.uni-karlsruhe.de).

Fernandez, A.L. (2005) **Comparative Study of Disaster-Related Science and Technology Policies in Five Countries: A Discussion Paper** (EDM Technical Report No. 20). Earthquake Disaster Mitigation Research Institute, Kobe.

Fernandez, A.L., N.R. Britton, J.C. Fernandez, and Z. Pooyan (2004) Comparative study of institutional arrangements in urban disaster reduction management. Proceedings. First Beijing Haidian International Forum for Earthquake Prevention and Disaster Mitigation, Beijing, Nov. 1-3, pp. 152-172.

Fernandez, A.L., J.C. Fernandez, N.R. Britton, J.C. Fernandez, and Z. Pooyan (2005) Pilot evaluation of the participatory city workshops in disaster risk management. Japan-US Joint Symposium for Natural Disaster Mitigation, Kobe, January 24-25, 2005.

Hiraishi, Tetsuya, Kenji Harada, and Fumihiko Imamura (2003) Tsunami disaster mitigation for Asia and Pacific Region: applicability of tsunami prevention with greenbelt. Fifth Multi-lateral Workshop on Development of Earthquake and Tsunami Disaster Mitigation Technologies and their Integration for the Asia-Pacific Region, EDM Technical Report Series No. 16 (CD-ROM). Earthquake Disaster Mitigation Research Institute (EDM), Miki.

Mattingly, Shirley (2002) Policy, legal and institutional arrangements. Proceedings. Regional Workshop on Best Practices in Disaster Mitigation, Sept. 24-26, 2002, Bali, pp. 19-36.

Mattingly, Shirley, Neil R. Britton, and F. Bendimerad (2005) Implementing sound practices for disaster risk management in complex urban environments (megacities): Metropolitan Manila, Mumbai and beyond. 1st International Conference on Urban Disaster Reduction. Kobe. 18-21 January 2005 (available at: http://www.edm.bosai.go.jp/team4/3cd/index).

Pearson, Helen (2005) Scientists Seek Action to Fix Asia's Ravaged Ecosystems. **Nature**, Vol. 433, January 13, 94.

Quarantelli, E.L. (1998) **Major Criteria for Judging Disaster Planning and Managing and Their Applicability in Developing Societies**. Disaster Research Center, University of Delaware, Newark.

Ritchey, T. (2002) Modelling Complex Socio-Technical Systems Using Morphological Analysis (available at: http://www.swemorph.com/downloads.html).

Ritchey, T. and C. Kaunitz (2005) Evaluating a Swedish airborne combat capability using computer supported morphological analysis. 10th International Command and Control Research and Technology Symposium, McLean, Virginia, June 13-16, 2005 (available at: http://www.swemorph.com/downloads.html).

La Trobe, Sarah and Davis, Ian (2005) **Mainstreaming Disaster Risk Reduction: a Tool for Development Organisations**. Tearfund, Middlesex, UK.

UN/ISDR (United Nations/International Strategy for Disaster Reduction) (2004) Living with Risk. United Nations, Geneva, p. 256 (available at http://www.unisdr.org/eng/about_isdr/bd-lwr-2004-eng-p.htm).

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ACKNOWLEDGMENTS

In addition to the authors, the workshop was attended by: Dr. Fouad Bendimerad (Hazard management, USA), Chairman, Earthquake and Megacities Initiative (EMI); Dr Raymond Burby (Land-use management/hazard management, USA), Professor of City & Regional Planning, University of North Carolina at Chapel Hill; Ms Kerstin Castenfors (Crisis management., Sweden), Deputy Director of Research, Dept. of International Security Studies (Division of Defence Analysis), Swedish National Defence Research Agency (FOI); Dr Ian Davis (Development and sustainability, United Kingdom), Visiting Professor in Cranfield University, and Visiting Fellow in York and Oxford Brookes Universities; Ms Shirley Mattingly (Disaster management/public administration practice and public policy, USA), Project Director, Cross-Cutting Capacity Development Program, EMI. The authors thank them all for their active collaboration. The contribution of Jeannette Fernandez-Castro, coordinator for Analysis of Knowledge and Practice component of the 3cd Program in the discussions concerning methodologies, was highly valued.

(Note: Neil Britton and Antonio Fernandez contributed to the workshop in the field of integrated risk management/disaster management theory and practice, and environmental planning and sustainability, respectively. Tom Ritchey was the workshop facilitator.)