FORMAL MODELS FOR CONFLICT RESOLUTION AND CASE STUDIES

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Summary

A rich range of formal models is available for systematically studying conflict as well as other types of decision making situations. These mathematically-based models were scientifically developed in fields such as operational research, systems engineering, game theory, systems analysis and other systems sciences for systematically modeling and analyzing real-world decision problems. When investigating the conflict arising over pollution caused by a freighter illegally dumping used oil in a lake, decision makers may employ a range of physically-based models for describing the physical, chemical and biological aspects of the effects of the pollution and alternative procedures for cleansing the lake, and they may utilize conflict resolution techniques for understanding how to resolve justly the strategic aspects of the problem. Hence, they

can select appropriate physical and societal modeling methods from a toolbox containing a diverse variety of formal mathematical models. Specific kinds of formal models that can be utilized for studying a wide range of conflict situations include the graph model for conflict resolution, drama theory, metagame analysis, hypergame analysis, game theory models of negotiation and arbitration, multiple objective decision making methods, cooperative game theory techniques for cost allocation, and verification theory methods. When implemented as user-friendly programs called decision support systems, these methods can be conveniently applied to actual problems by practitioners and researchers. Moreover, one may wish to use formal decision models for conflict in conjunction with a general procedure for negotiation, mediation or arbitration such as interest-based negotiation. Additionally, formal models for conflict resolution possess many inherent advantages for enhancing the decision making process and putting the strategic aspects of conflict into proper perspective. In particular, a formal conflict model clearly structures the key characteristics of a given dispute in terms of factors such as decision makers, courses of action or options available to each participant, and each decision maker's preferences among the possible states or scenarios that can take place. Stability analyses, founded upon a calibrated conflict model, can be employed for forecasting potential resolutions or equilibria to the conflict through the investigation of the strategic effects of mathematically defined moves and counter moves among decision makers as they jockey for position during the evolution of the dispute. By using a formal model, one can investigate "what-if" questions in sensitivity analyses to determine, for instance, how changes in the preferences of one or more decision makers influence potential resolutions. Hence, for a current conflict, a formal conflict analysis provides a precise language of communication for discussing the conflict with others and better understanding of the strategic ramifications of actions that are taken now and over the course of the dispute. Improved communication and understanding can lead to enlightened cooperation which in turn may permit a win/win resolution that is both equitable and sustainable.

1. Introduction: Modeling Reality

1.1. Types of Models

In general terms, a *model* is a description or representation of a system or system of systems. A particular model attempts to capture the key characteristics of the system being studied so that the system can be better understood and hence informed decisions can be made about the system. Because a model is not the actual system, a model is always an approximation to and simplification of reality.

A model can be expressed in different ways and, therefore, can appear in a variety of forms. Suppose, for instance, one is examining a complex conflict that arose over the illegal dumping of used oil by a freighter traveling across Lake Ontario, which is one of the Great Lakes shared by Canada and the United States (see the map of the Great Lakes Basin given as Figure 1 in the Theme-level Paper on *Conflict Resolution*). One way to model this dispute is simply to describe verbally or in writing the conflict occurring among the decision makers consisting of the captain and crew of the freighter, the owners of the ship, environmental agencies representing the governments of both the USA and Canada as well as the state of New York and province of Ontario, various environmental groups, fishing industry spokespeople and concerned citizens. Another means to model this pollution dispute is to draw a diagram to portray complex interactions taking place among the different decision makers and stakeholders. Actual negotiations that do occur may follow a descriptive model for interest-based negotiations such as the useful approaches described in chapters under *Approaches to Conflict Resolution*. Moreover, it may even be possible and desirable to employ mathematical models to describe various aspects of the negotiation process. In fact, often an array of negotiation or conflict models can be selected from a toolbox of models to properly model complex negotiation processes that may change radically over time as the conflict matures in a highly dynamic and dramatic fashion to its final outcome.

1.2. Decision Making under Conflict

A conflict such as the oil pollution dispute in Lake Ontario not only involves stakeholders who are part of a complex societal system but also affects the physical systems supporting the environment in which society lives. The oil spill mentioned in Section 1.1, for instance, may harm various fish and other biological species in Lake Ontario and cause a deterioration of the quality of drinking water for communities that withdraw water from Lake Ontario close to and downstream of the spillage site. Accordingly, different physical systems models may be used to ascertain how the pollution may adversely affect the receiving environment and how cleanup measures may rectify the problem.

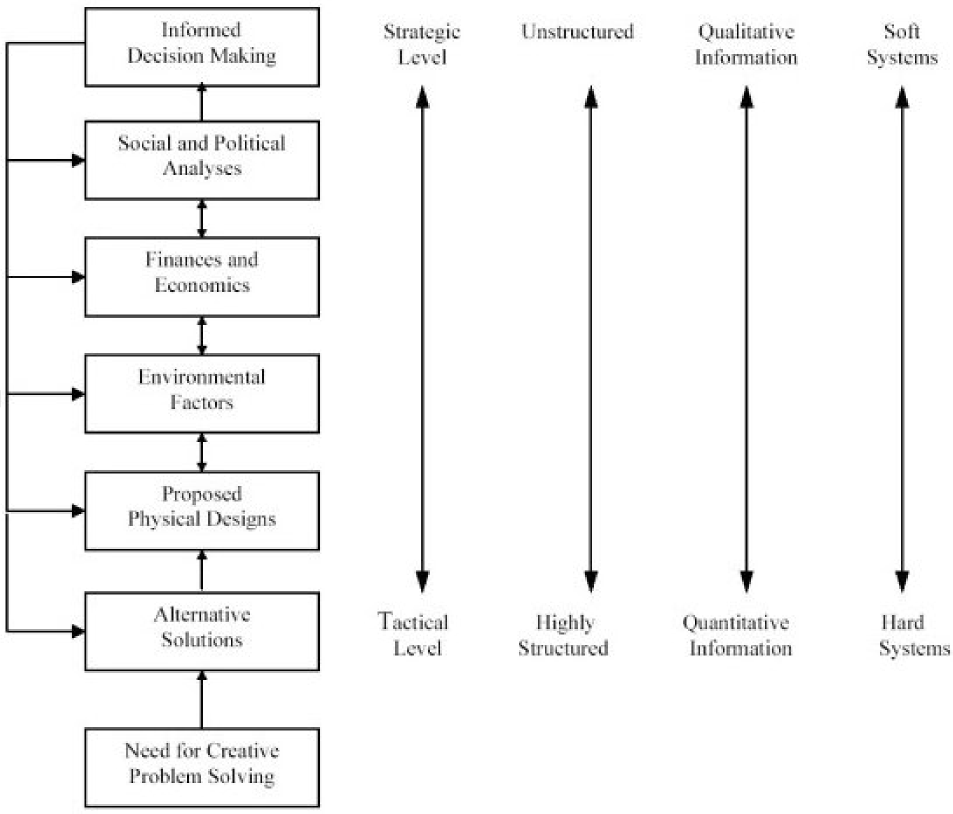

Figure 1: A systems design approach to decision making

Suppose that the oil pollution spill motivated Canada and the United States to devise improved methods for cleaning up oil and other types of pollution spills in the Great Lakes. Figure 1 summarizes the main facets of an encompassing systems design approach to enlightened decision making when an appropriate design must be selected or an operational procedure chosen for solving a given problem. For the case of deciding upon a suitable procedure or set of approaches for getting rid of a pollution spill, one must select from a range of potential solutions for meeting the multiple objectives of various interest groups. Potential solutions include surrounding the spill area with booms and subsequently pumping out the pollutant, adding chemicals to lessen the detrimental effects of the spillage, letting natural processes break down the pollutants, and various combinations thereof. Whatever the situation, the left-hand portion of the figure displays the main factors that must be considered for selecting a suitable design. In addition to a sound physical design, any alternative solution must be assessed with respect to environmental, financial and economical as well as social and political feasibilities. To assist in these evaluations, appropriate *techniques* from Systems Engineering and Operational Research (see Section 2.1) can be employed throughout the decision making process. For instance, stochastic differential equations describing the spread of the plume coupled with biochemical and optimization models can be utilized for finding optimal physical designs that satisfy weighted multiple objectives subject to environmental, financial and economical constraints. The social and political viability of various solutions can be assessed by using a technique such as the graph model for conflict resolution. The top cell in Figure 1 indicates that output from all of the analyses provides information to assist decision makers in eventually making an overall decision. As shown by the feedback arrows on the left in Figure 1, additional studies can be carried out as required to obtain an enhanced understanding of the problem and perhaps create an even better solution or some combination of solutions already considered. Moreover, the decision making procedure of Figure 1 is not restricted to design but could also be used, for instance, to develop improved operating rules for an existing system.

The right hand section of Figure 1 depicts characteristics that are embodied in the hierarchical framework of the decision making process. Notice that as one goes from the tactical level of decision making to the strategic level, the problem changes from being highly structured, quantitative, and hard, to being unstructured, qualitative, and soft. Because of this and other reasons, one must select an appropriate set of systems tools to investigate all relevant aspects of the system being studied. To compare alternative solutions to a problem that are evaluated according to both nonquantitative and quantitative criteria from one decision maker's viewpoint, one can utilize an appropriate, multiple-criteria, decision-making technique (see chapter on *Multiobjective Decision Making in Negotiation and Conflict Resolution* by Anderson, Hobbs and Bell). When modeling strategic interactions among decision makers, especially at the strategic level where information tends to be unstructured, more qualitative, and soft, one can employ the graph model for conflict resolution (refer to the chapter on *The Graph Model for Conflict Resolution* by Hipel, Kilgour and Fang, as well as to the chapter on *Misperceptions and Hypergame Models of Conflict* by Wang and Hipel) or drama theory (see the chapter on *Drama Theory and Metagame Analysis* by Howard and the book by Bryant (2003)). By properly addressing all key aspects of decision making, society can arrive at decisions that are more equitable to all parties involved and which fall within a sustainable development framework.

1.3. Developing Societal and Physical Systems Models

In reality, an array of both mathematically-based and nonmathematical models can be employed for investigating problems falling within the decision making framework in Figure 1. As already mentioned for the spilling and cleanup of oil pollution in Lake Ontario, a toolbox of both *societal systems* and *physical systems models* is available, or can be developed, for systematically studying the problem under consideration in order to enhance the decision making process. The purpose of Figure 2 is to emphasize that these societal and physical systems models, or some hybrid combination thereof, can be utilized in an integrative fashion for capturing the key characteristics of the realworld problem for which realistic and responsible solutions are being sought (see Hipel et al. (2008a) for further details). In systems modeling, one tries to describe complex factors such as the overall performance and properties of the complete system, individual components of the system and dynamic connections among these components, and synergistic effects bursting forth at higher levels as a result of these components interacting together.

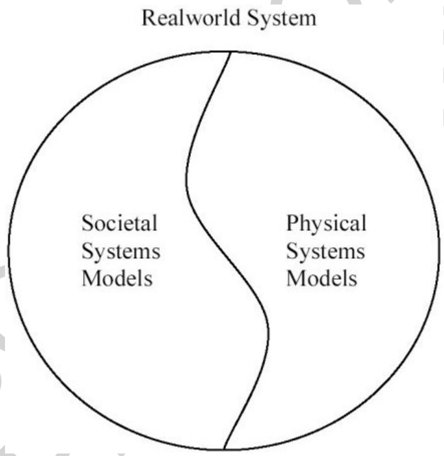

Figure 2: The duality of systems modeling of a realworld problem

When developing a *formal model* for explaining a part of the system problem, such as one specific component, there are some key modeling principles that one should keep in mind. As stressed at the start of Section 1.1, an important fact to remember is that a model is always an abstraction of reality that is developed for the main purpose of allowing human beings better to comprehend the problem and thereby ultimately make better decisions. Accordingly, as portrayed at the top of Figure 3, when designing a societal or physical model, or some combination thereof, one must first decide upon the key characteristics of the problem or phenomenon one wishes to incorporate formally into the model. For instance, key underlying properties observed in a conflict situation include the presence of two or more decision makers, the options or courses of action available to each decision maker, as well as the relative preferences among the possible scenarios or states that would occur as a result of each decision maker possibly implementing powers or options available to him or her. Subsequently, as depicted in the second enclosement from the top in Figure 3, one would wish to design a theoretical model based on definitions that reflect the key characteristics of the realworld problem and the type of information that is available for calibrating the model.

For instance, in a social conflict taking place in the realworld, it may only make sense to assume relative or ordinal preferences for each decision maker rather than real numbers (see Section 2.2.1 for a discussion of different kinds of preferences). In a social situation where a polite host asks whether you would like to have tea or coffee for a refreshment you may reply that you prefer to drink tea – you would certainly not respond that your utility values for tea and coffee are 6.95 and 4.62, respectively! Your host would probably look at you with a puzzled gaze and ask you to leave. Hence, one would design a conflict model that can handle relative preference information since this is the type of preference information that can be realistically obtained.

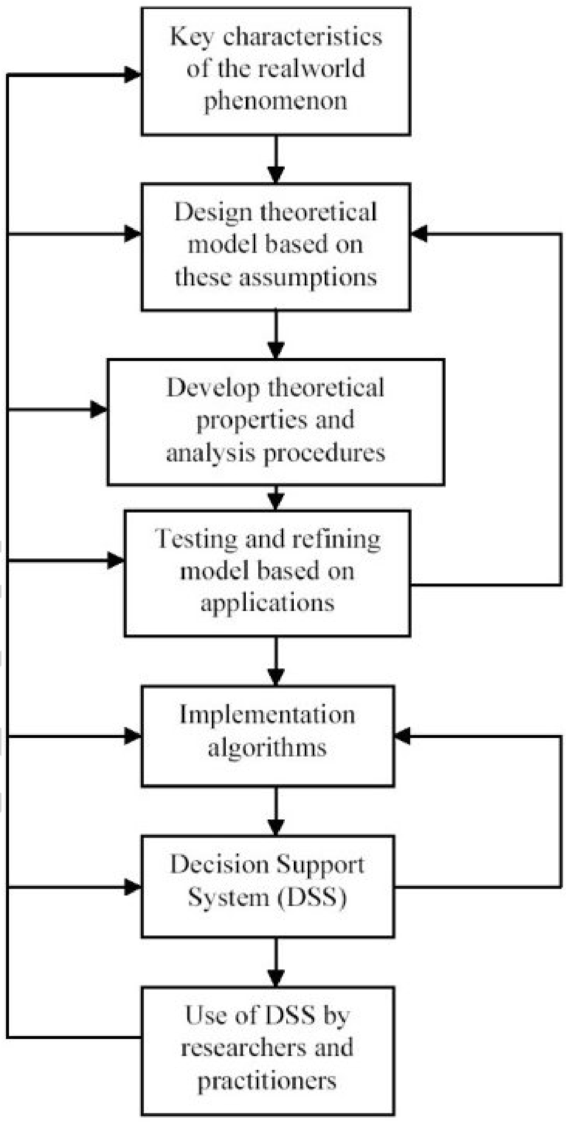

Figure 3: Developing a systems model

After the model being built is mathematically defined based on a range of assumptions or *axioms* that have direct connections to the main features of reality and available information, one could study various mathematical properties of the model in terms of useful theorems. When a conflict model is theoretically constructed, one may wish to prove an existence theorem that states that the model always predicts at least one equilibrium or resolution to a conflict, since in reality something always happens even if it is the maintenance of the status quo situation. The execution of mathematical calculations using the underlying model structure as a platform is referred to as *analysis*. Whatever the case, as indicated in the fourth box from the top in Figure 3, one should always test and refine a tentatively designed model based upon practical applications of what actually occurs in the realworld. As shown by the higher feedback arrow on the right in Figure 3, knowledge gained by experimentation with real problems can be used to improve the mathematical design of the theoretical model. One should always "twist" the mathematics to fit reality and not vice versa.

In order to permit the mathematical model to be widely accessible for use by researchers and practitioners, one must design a user-friendly computer programming package popularly referred to as a *Decision Support System* (DSS). The terminology DSS is employed because any model of reality is really meant to support decisions in a meaningful fashion and not stipulate what must be done (see Section 3 for a discussion of DSSs for conflict resolution). If every model that has ever been or will be developed is, by definition, an approximation to reality, then, without exception, human beings should always be in charge to interpret the results of modeling and analyses using those models, before they make final decisions, which hopefully will be ethical and responsible. Imagine what could have occurred in the Cuban Missile Crisis of 1962 if President Kennedy of the United States of America had blindly followed extreme military advice and modeling results that recommended an immediate nuclear strike against the partially constructed Soviet rocket-launching sites in Cuba. For one thing, this article would probably never have been written. Rather, President Kennedy wisely listened to the suggestions of a wide spectrum of advisors armed with their own studies and years of experience, to come up with a reasonable resolution that averted a nuclear holocaust. One must also acknowledge the prudence of Premier Kruschev of the Union of the Soviet Socialist Republics who removed the Soviet missiles from Cuba after an American naval blockade stopped military shipments to Cuba and after receiving an American promise never to invade Cuba.

Going back to Figure 3, notice that prior to programming a DSS one often requires implementation *algorithms*. For example, often when using formal models one runs into problems of large size and, hence, ideas from combinatorics are utilized to control and manage them using specialized algorithms, which are programmed into the DSS. Algorithms are also needed for estimating or calibrating the parameters for a given model and calculating analytical results based on the calibrated model. For instance, after a conflict model is expressed in terms of decision makers, options and preferences for each decision maker, stability algorithms are implemented for calculating specified moves and counter-moves that could take place to ascertain if a specific state is stable for a given decision maker according to a specific mathematically-defined stability concept. If the state is stable for all of the decision makers, it constitutes a potential resolution or equilibrium. As indicated by the lower feedback arrow on the right in Figure 3, the DSS and associated implementation algorithms are usually developed together in an iterative fashion. Finally, as can be seen at the bottom of Figure 3 and the feedback arrows on the left hand side, valuable advice from users of the DSS can be employed for continuously improving or expanding the theory and subsequently updating the DSS.

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Biographical Sketch

Keith W. Hipel is University Professor of Systems Design Engineering at the University of Waterloo, Waterloo, Ontario, Canada, where he is the Director of the Conflict Analysis Group. Dr. Hipel thoroughly enjoys teaching and is a recipient of the Distinguished Teacher Award and the Award of Excellence in Graduate Supervision from the University of Waterloo. His major research interests are the development and application of conflict resolution, multiple objective decision making, and time series analysis techniques from a systems design engineering perspective. The main application areas of these decision technologies are water resources management, hydrology, environmental engineering and sustainable development. Dr. Hipel is the author or co-author of four books, eleven edited books and close to 200 journal papers. He is Fellow of the Royal Society of Canada (FRSC), Canadian Academy of Engineering (FCAE), Institute of Electrical and Electronics Engineers (FIEEE), International Council on Systems Engineering (FINCOSE), Engineering Institute of Canada (FEIC), and American Water Resources Association (FAWRA). Dr. Hipel is also a recipient of the Norbert Wiener Award from the IEEE Systems, Man and Cybernetics (SMC) Society, Outstanding Contribution Award from the IEEE SMC Society, title of Docteur Honoris Causa from École Centrale de Lille, W. R. Boggess Award from AWRA, and University of Waterloo Award for Excellence in Research. He has held a Canada Council Killam Research Fellowship, Monbusho Kyoto University Visiting Professor Position, Stanley Vineberg

Memorial Visiting Professorship, Centre National de la Recherche Scientifique (CNRS) Research Fellowship and Japan Society for Promotion of Science (JSPS) Fellowship. Moreover, he is a Professional Engineer and has carried out consulting activities with engineering firms, government agencies, and utilities in many countries. Finally, he is Vice President of the Canadian Academy of Sciences (2007-2009) and an Associate Editor of eight international journals, including the IEEE Transactions on Systems, Man and Cybernetics, as well as Group Decision and Negotiation.