Chapter 2
Decision-Making in Perspective

2.1 Overview

The goal of this chapter is to put the field of conflict resolution and associated domain of game theory into perspective so that a reader will be able to fully appreciate the inherent value of utilizing Graph Model for Conflict Resolution (GMCR) as a highly informative and operational means for studying actual social conflict that does take place in reality. Within Sect. 1.2 of the previous chapter, some of the key ideas underlying the formal investigation of conflict are discussed. Within this book, the detailed explanation of how these concepts are defined and operationalized using real-world examples are presented in subsequent chapters. In Sect. 2.2, the evolution and development of a rich variety of game theory methods is put into perspective to highlight the important and central role that GMCR plays for sensibly and flexibly modeling and analyzing social conflict. An insightful classification of game theory methods permits one to understand situations in which various approaches can be employed, with GMCR being the key methodology for formally studying societal conflict occurring in many different disciplines such as engineering, law and military science.

Two key fields in which a wide range of formal decision-making tools have been developed since the late 1930s and 1940s are Operations Research (OR) and Systems Engineering, respectively. The history and development of decision technologies within these two dynamic fields of study are presented in Sects. 2.3.1 and 2.3.2 for OR and Systems Engineering, respectively. To permit a given decision-making approach to be applied to practical problems, a user-friendly set of programs and associated databases should be made available in what are called Decision Support Systems (DSSs) outlined in Sect. 2.3.3 and described in detail for GMCR in Chap. 10. As explained in Sect. 2.4.1, a System of Systems (SoS) interpretation of reality provides a solid foundation on which an informative decision tool like GMCR can be utilized, since DMs or agents compete and cooperate with one another within and among systems. As discussed in Sect. 2.4.2, responsible governance can be achieved and

H. Xu et al., *Conflict Resolution Using the Graph Model: Strategic Interactions in Competition and Cooperation*, Studies in Systems, Decision and Control 153,
https://doi.org/10.1007/978-3-319-77670-5_2

key systems values like robustness, sustainability and fairness can be met, when this is carried out using integrative and adaptive management concepts.

2.2 Game Theory Methods: Classifications

As explained in the next subsection, because conflict is so ubiquitous in society, researchers and practitioners have developed a rich range of conflict analysis approaches for investigating many different kinds of situations. In fact, to put conflict analysis methods into perspective, an insightful way for classifying conflict analysis or game theory techniques is put forward in Sect. 2.2.2. By knowing the key characteristics of a specific real-world dispute being studied, one can select an appropriate game theory method, or set of techniques, that has the structural capabilities for modeling and analyzing it.

2.2.1 The Evolution of Game Theory Methods

As vividly described in Sect. 1.1, conflict is an inherent characteristic of human nature which dictates how individuals, groups of people, organizations and nations interact with one another. For instance, warfare is recorded in the history of early civilizations that existed in Mesopotamia, China and India, up until the present time when nasty regional wars have been taking place in the Middle East for many decades. International companies in the automobile industry, electronics, information technology and many other fields are currently fiercely competing on a global basis to capture larger market shares in each of these areas. On a personal level, people might still disagree over how work should be fairly allocated when completing a given task as mundane as cleaning the rooms in a house.

The fact that conflict is so prevalent attracted the attention of scholars in many fields of study. Because conflict involves people, researchers in the social sciences were among the first to explain and categorize conflict in fields such as sociology, law and economics. Attempts to formalize the study of conflict by developing mathematical models of disputes are more recent. The areas in which formal mathematical models of conflict have been developed are often collectively referred to as game theory. Early work in game theory can be traced back to the year 1654 when the French mathematicians Pierre de Fermat and Blaise Pascal studied a specific kind of parlor game and established the foundations for the theory of probability. Nonetheless, it was the groundbreaking work of von Neumann (1928) and, particularly, von Neumann and Morgenstern (1944, 1953) that decisively brought game theory into the modern era as a distinct domain of mathematical enquiry having a rich range of conflict problems to tackle. Moreover, since conflict arises in virtually every field of human endeavor, contributions to game theory have been made by experts working in many areas. As is explained in Sect. 2.3, mathematicians, scientists and engineers working in the fields of Operations Research and Systems Engineering have designed a wide range of formal decision-making methods including various game theory techniques. Operations Research was started by the British military just prior to the start of World War II (WWII) in Europe while Systems Engineering was largely initiated shortly afterwards. In addition, since the cessation of hostilities after WWII, there has been a great proliferation of research in game theory. As a matter of fact, it is difficult to keep track of what has been accomplished in game theory across a large number of fields and how to put the many contributions to game theory into perspective.

2.2.2 *Classifying Formal Game Theory Techniques*

To permit researchers and practitioners to wisely select the most appropriate game theory tools to utilize for addressing different kinds of conflict problems and for deciding upon where there are needs for refining and extending game theory tools as well as designing new methods, one must be able to classify game theory techniques in meaningful ways. In general, one requires useful criteria for categorizing game theory methods. Some of these criteria include types of preference information, number of decision makers, number of options or strategies, size of the conflict, kinds of human behavior under conflict, types of available information, kinds of uncertainty, and level of cooperation which can range from highly noncooperative competition to increasing levels of cooperation ending at a universal coalition (Fang et al. 1993, Sect. 1.4). By being aware of the criteria under which game theory techniques are categorized as well as the key characteristics of an actual conflict being investigated, one can choose an appropriate set of game theory tools that possess the theoretical capability, as expressed by the criteria, to model the main characteristics of the dispute. In other words, one makes a one-on-one linkage between model criteria and problem characteristics to select the appropriate set of tools. Additionally, one can discover a gap in the literature which indicates where more research is needed if tools are not currently available to address certain problem characteristics.

As suggested by Hipel and Fang (2005), an especially informative way to classify formal game theory methods is according to type of preference. Figure 2.1 displays a genealogy of game theory methods for categorizing game theory techniques with respect to relative and cardinal preferences. As mentioned in Sect. 1.2.2, when a person asks a friend whether she would like to have coffee or tea to drink, the companion would probably respond that she would prefer to have a cup of coffee. If having coffee or tea is equally preferred, the person may respond that it does not matter which drink you serve me. This is what is called a relative preference and it constitutes a nonquantitative way of expressing a preference. On the other hand, if utility values conveyed as real numbers or benefits given as dollars are used to indicate preference, these are called cardinal preferences. It does not make sense to state that a cup of coffee is worth 6.2 utility units to a person and tea 2.8 in place of simply stating that she prefers to drink coffee. However, when the profits made by a

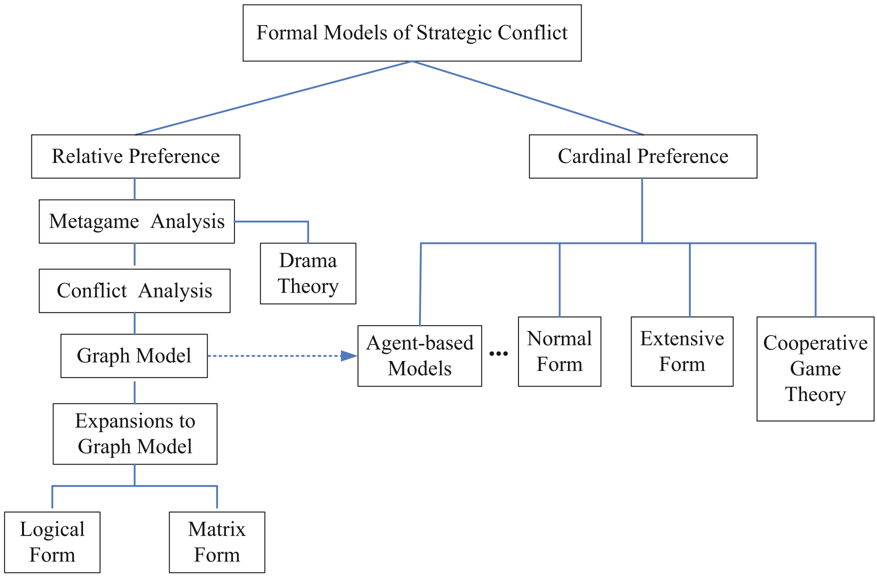

Fig. 2.1 Genealogy of formal multiple participant decision-making models

company in producing two different products are 100 and 35 dollars then it may be meaningful to use cardinal numbers given as dollars to represent the preference of the company to manufacture more of the product which brings in higher profits. Even though the qualitative methods listed in the left branch in Fig. 2.1 only depend upon relative preference information, these techniques, like the ones in the right branch, constitute formal mathematical game theory techniques. In fact, as explained in upcoming chapters in the book the kinds of mathematical concepts used to build the qualitative game theory methods come from set theory, logic, graph theory and matrix algebra - the mathematics for expressing relationships.

The focus of this book is the Graph Model for Conflict Resolution (GMCR), which is given under relative preferences in the left branch in Fig. 2.1. These game theory methods listed in the left branch are especially useful for modeling and analyzing real-world social conflicts such as environmental disputes, trading conflicts among nations and an argument between neighbors over where the fence between their properties should be located. When reading from the top to the bottom of the left branch, the earliest method created under this category is the pioneering technique of metagame analysis which was developed by Howard (1971). Subsequently, Fraser and Hipel (1979, 1984) expanded the scope of metagame analysis through the development of a methodology called conflict analysis which was further significantly enhanced by Kilgour et al. (1987) and Fang et al. (1993) in the construction of the comprehensive approach labelled as GMCR. As indicated at the bottom of the left branch, GMCR has been further improved by the design of a matrix form of this approach, which is utilized throughout this book as well as by many other enhancements presented in Chaps. 3–9. Moreover, GMCR has been significantly broadened in scope by the addition of many other developments presented in Chaps. 4–9 plus those mentioned in Sect. 10.3. Over the years, summary papers describing the capabilities of the GMCR methodology as well as opportunities for future development have been written (see, for instance, Hipel et al. (2003) and Kilgour and Hipel (2005, 2010)). The original logical form for logically explaining stability calculations in terms of moves and countermoves has been further improved by the design of a matrix form of this approach used extensively in this book and is especially important in carrying out stability calculations in the engine of a DSS for GMCR described in Chap. 10. Additionally, as depicted in the left branch, metagame analysis was expanded by Howard et al. (1992), Howard (1999) and Bryant (2003, 2015) through their development of a procedure called drama theory for nonquantitatively modeling the dynamic aspects of conflict based on the metaphor of a drama.

In their book entitled "Theory of Games and Economic Behavior", von Neumann and Morgenstern (1944, 1953) mainly deal with quantitative game theory methods, which are calibrated using cardinal preferences and often referred to as classical game theory methods. Three popular kinds of techniques from classical game theory are normal form, extensive form, and cooperative game theory which are listed in the right branch drawn in Fig. 2.1. In classical normal form, one assumes that two or more DMs interact one time only. The normal form of the game is defined in Sect. 3.1 in this book under the assumption of having relative preferences, rather than cardinal. A convenient way to display the normal form is to use a matrix in which the row player or DM controls the strategies represented by the rows while the column player is in charge of the column strategies. Each cell in the matrix represents a possible scenario or state. Within the extensive form, multiple interactions among DMs are depicted using a tree-like structure that keeps track of all possible evolutions of the game.

Cooperative methods are used to examine the interaction of DMs who must cooperatively decide how to fairly divide a "pie" or some resource in an equitable fashion. These methods are often employed to analyze coalition formation, voting problems or optimal resource allocation procedures. The Cooperative Water Allocation Model (CWAM), for example, constitutes a large-scale optimization model based on ideas from cooperative game theory, economics and hydrology to fairly allocate water among competing users in a river basin (Wang et al. 2003, 2007, 2008a, b, Hipel et al. 2013b). Based on a systems approach, CWAM considers not only the physical systems consisting of hydrological and environmental factors but also the societal system. Moreover, CWAM has been expanded to handle demand-side management to promote water use efficiency (Xiao et al. 2016). Furthermore, CWAM has been successfully applied to fair water allocation problems in the South Saskatchewan River Basin located in the Canadian Province of Alberta (Wang et al. 2008a, b, Hipel et al. 2013b) as well as the Aral Sea region (Wang et al. 2007).

As shown in the central part of Fig. 2.1, another approach in which cardinal preferences are assumed is agent-based modeling. In this procedure, the actions and interactions of agents are simulated in order to assess their impacts on the overall system. Hence, this method can be employed to test whether or not a given policy will function according to expectations in practice. For example, one may wish to determine if a cap and trade method will significantly reduce the amount of greenhouse gases released by society into the atmosphere. Agent-based modeling can be interpreted as a bottom-up approach to performance assessment since it determines if individual decision-making units, often referred to as autonomous agents, interact in a way that causes the policy to meet its goals. As pointed out by Hipel and Fang (2005), researchers in agent-based modeling often directly import concepts from classical game theory for utilization in their formal analyses of rules or protocol governing the high level behavior of interacting agents as is done by Rosenschein and Zlotkin (1994). Therefore, Hipel and Fang (2005) recommended that solution concepts describing possible moves and countermoves among DMs within the GMCR paradigm be utilized in agent-based modeling for policy assessment. This was accomplished for the first time by Bristow et al. (2014) when they examined the responsible utilization of common pool resources such as water and the atmosphere in order to avoid a Tragedy of the Commons (Hardin 1968, Ostrom et al. 1994, 1999) in which a common resource is destroyed via entirely competitive rather than cooperative behavior. A dotted line showing the connection of GMCR to agent-based modeling is drawn in the central part of Fig. 2.1.

A number of books and papers have been written in which different approaches to game theory have been described and compared. For instance, Hipel (2009a, b) and Kilgour and Eden (2010) have produced edited books in which experts from many fields have written papers on a range of conflict analysis methodologies in group decision and negotiation for application in many different areas. The chapters in these handbooks largely concentrate on methodologies listed in the left branch of Fig. 2.1 but techniques coming under the right branch and elsewhere are also presented. Hipel and Bernath Walker (2011) and Hipel et al. (2016) provide an overview of the employment of conflict analysis methods in environmental management that span both branches in Fig. 2.1.

2.3 Formal Decision-Making Techniques

As discussed in Sect. 2.2 and depicted in Fig. 2.1, game theory is comprised of a rich range of mathematically-based techniques for formally investigating conflict. Fortunately, a wide variety of formal decision-making tools have been developed for investigating many different kinds of decision situations. Because decision-making arises in many areas of human endeavor, from engineering design to international trade, approaches to tackling decision problems have been put forward by researchers and practitioners from many different disciplines. Two specific disciplines, or fields, in which many different types of formal or mathematically-founded techniques have been developed starting about the time of World War II (WWII) are Operations Research and Systems Engineering. Accordingly, a brief history of these two disciplines along with an overview of the types of tools that have been developed within them are put forward in the next two subsections, respectively. The reason why it is important to be aware of the existence of a valuable range of formal tools is because when addressing tough systems problems, such as those arising in energy use and climate change, usually a number of specific tools can be selected for assisting in realistically addressing a particular problem. Moreover, due to their inherent mathematical design, most of these methods are readily available as decision support systems containing comprehensive computer programs and databases for permitting them to be conveniently applied to practical problems, as outlined in Sect. 2.3.3 and explained in more detail in Chap. 10, including issues related to governance discussed in Sect. 2.4.

2.3.1 Operations Research

Operations Research (OR) or Operational Research, as the British call OR, constitutes a systematic approach for scientifically solving real-world problems. The term "scientific" is used in the definition because only formal techniques that actually work in practice for enhancing decision-making are utilized, often in the face of sparse information and high uncertainty (Kimball and Morse 1951, Hipel 1981, Ravindran et al. 1987). OR was originally conceived by the British as a response to a potential military threat just before the outbreak of WWII in Europe. As described by Lardner (1979), the British military was concerned about how to defend the United Kingdom against potential air attacks from Germany since German bombers could reach the UK in a very short period of time. In fact, by the mid-1930s Germany was the dominant economic and military power in continental Europe and it was acting very aggressively against its neighbors in response to the unfair treatment that it thought it received under the Treaty of Versailles signed in 1919 just after World War I (WWI). By 1935, radar was recognized by the British as a viable means of detecting enemy aircraft before they reached the British Isles. Accordingly, the British established a system of radar bases in the southern and eastern parts of England. When the British tested their system of radar bases against mock air attacks from their own air squadrons launched from air bases in France, the system failed to work. There were, for instance, poor communication among radar stations and a lack of systematic defensive strategies from fighter aircraft that took off from Royal Air Force facilities in England to disrupt or stop the attack. As a consequence, in July 1938, research into the operational aspects of radar systems was initiated. The effectiveness of OR was confirmed by the successful air exercises carried out during the summer of 1939.

The first major employment of OR in WWII actually saved the UK from defeat by Germany. In particular, at the outbreak of WWII on September 1, 1939, the OR Section was attached to the Headquarters of the Royal Air Force Fighter Command. On May 10th, 1940, Winston Churchill replaced Neville Chamberlain as Prime Minister of the UK. On the same day, the Germans launched Fall Gelb (Operation Yellow) which led to the rout of the French army and British Expeditionary Forces by the Wehrmacht (refer to Bennett and Dando (1977, 1979) for a history of the Battle of France and to Fraser and Hipel (1984), Sect. 4.2, for a conflict analysis of the strategic surprise used in Fall Gelb when the main German forces unexpectedly attacked through the Ardennes). Subsequently, from July 10th, 1940 to September 15th, 1940, the German Luftwaffe attempted to defeat the UK by aerial bombardment during the Battle of Britain. Largely because of OR, Germany was not successful in defeating the UK and in reality suffered massive losses of military aircraft and personnel. OR scientists can be accredited with saving the Royal Air Force from being obliterated during the Battle of France so it could survive to be victorious in the Battle of Britain. A relatively small OR study demonstrated that based on current losses and replacement rates at that time, the Germans would have destroyed the entire Royal Air Force within two weeks. A graphical presentation of these findings on May 15th, 1940, convinced Churchill not only to stop sending more fighter squadrons to France but also to withdraw all of the British air squadrons which were in France at that time.

In addition to the air force, the other UK armed services also employed OR teams for solving specific large-scale military problems. A well-known naval illustration is how allied shipping losses as a result of attacks by German submarines in the North Atlantic against ships transporting supplies and personnel to the UK from Canada and the United States were reduced by increasing the size of escorted convoys. After the United States entered the war on December 7, 1941 as a direct result of the unexpected Japanese aerial attack on Pearl Harbor by planes launched from aircraft carriers, the American armed forces used OR in its military decision-making.

Besides their OR teams, both the British and American armed forces utilized the talents of gifted mathematicians, scientists and engineers to break encoded messages sent by the Germans and Japanese, respectively. In particular, at Bletchley Park located 80 km northwest of London, the location of the UK's Government Code and Cypher School, mathematicians like Alan Turing and William "Bill" Tutte helped to break the German Enigma and Lorenz ciphers, respectively. What was called Ultra intelligence at Bletchley Park may have shortened the war by as much as two to four years (Aldrich 2010, Briggs 2011, Grey 2012). In the Pacific arena of the war, personnel at the United States Navy's Combat Intelligence Unit were able to decipher encoded messages sent by the Japanese Navy throughout the war and thereby knew about Japanese naval maneuvers before they took place (Winton 1993, Benson 1997). Because of the deciphering of a message giving the flight plans of Admiral Isoroku Yamamoto, Commander-in-Chief of the Combined Japanese Fleet, American pilots in P-38 fighters killed Admiral Isoroku Yamamoto on April 18, 1943 by shooting down the plane carrying him as it was about to land at Bougainville in the Solomon Islands.

As explained by Fang et al. (1993, Sect. 1.4) and many other authors, OR is both an art and a craft. The art is composed of a general approach to solving complicated operational problems, whereas the craft component consists of a wide range of mathematical methods for furnishing reasonable findings when properly applied to specific problems. Methods that are commonly considered to be part of OR include optimization techniques such as linear, nonlinear and integer programming; probabilistic techniques like Markov Chains, queuing theory and certain kinds of

Table 2.1 Classification of decision-making models

		Objectives	
		One	**Two or More**
Decision Makers	**One**	**Most OR Models**	**Multiple Criteria Decision Analysis**
	Two or More	**Team Theory**	**Game Theory**

time-series models; and some game theory approaches. As is also the situation for the game theory methods mentioned in Sect. 2.2.2 and summarized in Fig. 2.1, there is a range of criteria that could be employed for categorizing OR techniques. In Table 2.1, OR techniques are classified with respect to two criteria: number of decision makers (DMs) and number of objectives. As indicated, many OR methods or models represent the perspective of one DM having a single objective. For instance, linear programming can be employed as an optimization tool by a company to minimize its costs expressed as a linear algebraic objective function which is minimized within a feasible region constrained by linear algebraic inequalities. Multiple criteria decision analysis (MCDA) methods (see, for example, MacCrimmon (1973), Keeney and Raiffa (1976), Saaty (1980), Hwang and Yoon (1981), Goicoechea et al. (1982), Vincke (1992), Roy (1996), Rajabi et al. (1998), Hobbs and Meier (2000), Belton and Stewart (2002), Chen et al. (2008), Chen et al. (2011), Hipel et al. (2009a), Kuang et al. (2015)) are purposefully designed for discovering the set of more preferred alternative solutions to a problem when the discrete alternatives are evaluated against criteria ranging from cost (a quantitative criterion) to aesthetics (a nonquantitative or qualitative criterion). The evaluations of the criteria for each alternative are indications of the achievements of objectives or preferences of the DM. Because many decisions in most fields ultimately involve making a discrete choice for a given DM, such as deciding upon the specific type of car to purchase, MCDA techniques have been applied to a diverse range of fields spanning from water resources (Hipel 1992) to energy problems (Hobbs and Meier 2000). This important set of tools is given as an example of a decision model containing one DM having two or more objectives as listed in the top right cell in Table 2.1.

As indicated in the bottom left cell in Table 2.1, team theory is an example of a technique having two or more DMs but only one objective since each team participating in a sporting event has the single goal or objective of winning. In a card game such as poker, each player possesses the single objective of winning the most money.

The focus of this book is the general decision-making situation in which there are multiple DMs, each of whom can have more than one objective. As indicated in the bottom right cell in Table 2.1, the game theory methods outlined in Sect. 2.2.2 and

Fig. 2.1 fall within this category. An example of a flexible game theory method is GMCR which constitutes the theme of this book and is contained in the left branch of Fig. 2.1. As explained in Sect. 2.2.2 and by authors such as Hipel (2009a, b) and Kilgour and Eden (2010), a wide variety of game theory methods have been developed over the years for tackling different kinds of multiple participant-multiple objective decision-making situations (Hipel et al. 1993). In fact, this is the category of OR for which there is great demand for the development of decision techniques but where OR researchers have devoted the least effort. Accordingly, a key goal of this book is to significantly extend the field of conflict resolution such that researchers and practitioners will possess more comprehensive tools for effectively addressing complex problems arising in multiple participant-multiple objective decision making.

The terminologies of normative and descriptive methods are often utilized for characterizing OR methods. A normative technique stipulates what a DM should do in order to reach a well-defined objective. For instance, the Cooperative Water Allocation Model (CWAM) mentioned in Sect. 2.2.2, which is formulated as an overall nonlinear programming model, can be optimized to specify how water can be fairly allocated among competitors in a river basin. Since fairness ideas from cooperative game theory are contained in CWAM, this model falls under the right branch in Fig. 2.1. Alternatively, a descriptive model captures the main characteristics of a problem in order to describe their relationships and a range of consequences that could occur. For example, conflict analysis techniques contained in the left branch of Fig. 2.1 can mainly be interpreted as being descriptive because they describe a variety of possible compromise resolutions as well as the various social interactions that can cause these equilibria to take place. Nevertheless, a conflict analysis method like GMCR can also be thought of as containing a normative component. This is because the findings of a GMCR investigation can be used to furnish a DM with a better understanding of the conflict under study and strategic advice on how to interact with his or her competitors in order to reach his most preferred equilibrium within the social constraints of the conflict. When a specific equilibrium is recommended for resolving a conflict, along with a particular path for reaching it, GMCR can be interpreted as being used in a normative fashion. Finally, to make both the descriptive and normative aspects of a conflict analysis study readily available, it must be implemented as a DSS, as outlined in Sect. 2.3.3 and explained in more detail in Chap. 10.

As pointed out earlier, OR was conceived and originally developed by the armed forces just prior to and throughout WWII to tackle urgent operational military problems as they arose or were anticipated. During the first few decades after the war, OR researchers and practitioners focused on designing highly mathematical and quantitative methods that are useful for addressing well-defined problems especially at the tactical level of decision-making. For instance, within an industrial organization, OR teams regularly employ mathematical programming techniques for solving difficult technical problems in resource allocation at the tactical level. Nonetheless, although some advances have been made more recently in developing formal techniques for utilization at the strategic level of decision-making, where the information base is often qualitative in nature, much work remains to be accomplished. Within and among most organizations, strategic decision-making almost always involves

Table 2.2 Two levels of decision-making

Tactical level	Stratagic level	References
Tactical	Strategic	Radford (1988, 1989), Rosenhead (1989)
Regular problem	Messes	Ackoff (1981)
Technical	Practical	Ravetz (1971)
Tame	Wicked	Rittel and Webber (1973)
Hard systems	Soft systems	Checkland (1981)
High ground	Swamp	Schon (1987)
Components	System or system of systems	Hipel et al. (2009b)

multiple DMs, each of whom has multiple goals. Accordingly, a key goal of this book is to assist in meeting this current need for extending the domain of OR.

Researchers and practitioners commonly refer to two major levels of decision-making: tactical and strategic. Moreover, many authors highlight the need for constructing more procedures for addressing less structured problems occurring at the strategic level. A range of labels that have been coined for describing these lower and higher levels are provided in the first and second columns of Table 2.2, respectively, along with references in the third column.

OR is the most widely known field for producing formal decision-making methods. Many of the problems studied using OR tend to be large-scale and highly complicated. Because of this, when investigating a specific problem often OR practitioners and researchers have backgrounds in many different disciplines and work as a team when addressing the various aspects of the overall problem using many different techniques. The team must obtain reasonable solutions in a scientific and expedient manner. Stated otherwise, the team must efficiently solve complicated well-structured problems in order to meet specified objectives. Due to the great success of OR for systematically solving tough problems, after WWII OR Societies were formed in many industrialized societies and associated OR journals were founded. For example, the world's oldest OR society was started in the UK as the Operational Research Club in April, 1948, which later became the OR Society in 1953. Since 1950, this society has been publishing the Journal of the Operational Research Society. In the USA, the Institute for Operations Research and the Management Sciences (INFORMS) publishes many journals for which the flagship journals are Operations Research and Management Science. The Group Decision and Negotiation Section of INFORMS produces its own journal entitled Group Decision and Negotiation. In Canada, the Canadian Operational Research Society publishes the journal called Information Systems and Operational Research (INFOR).

Outside of the military sciences, one of the first fields to take an OR and systems approach to problem solving was water resources. Hence, for instance, many applications and developments in OR can be found in journals such as Water Resources Research (published by the American Geophysical Union), Journal of Water Resources Planning and Management (American Society of Civil

Engineers) and the Canadian Water Resources Journal (sponsored by the Canadian Water Resources Association). Other disciplines in which OR is widely utilized and expanded include transportation, urban planning, systems design engineering, systems analysis (Miser and Quade 1985, 1988), management sciences, systems thinking (Checkland 1981), industrial engineering and business. Together the foregoing disciplines are often referred to as the "Systems Sciences". The comprehensive encyclopedia on systems and control edited by Singh (1987) contains definitions and explanations of decision-making techniques from the systems sciences, artificial intelligence, and elsewhere. A discipline or field that utilizes ideas from OR but goes well beyond that is Systems Engineering which is now described.

2.3.2 Systems Engineering

The key underlying philosophy of Systems Engineering is to tackle problems from a holistic or overall viewpoint. One must first see the entire "forest" before trying to solve a problem involving a specific "tree" which is, of course, a subset of the forest. This concept of envisioning a complete system connected to a problem, which is composed of interconnected components synergistically serving the overarching goals of the system is natural and very pleasing to the mind. In Japan, one can contemplate for hours while viewing a rock garden which consists of various sets of rock formations situated at satisfying but perhaps surprising locations in a sea of sand marked with intersecting flowing patterns. This is the way people like to view reality: artistically, systems thinking is Eastern in derivation but technically more Western. One of the first physical systems drawn in one of the most creative and insightful phases of all human history - the Renaissance - was the Hydrological Cycle depicted by the great Leonardo Da Vinci.

Among other authors, Hipel et al. (2009a) provided a comparison of OR and Systems Engineering. Because OR attempts to be scientific, it is founded upon reductionist concepts. Hence, OR attempts to understand a phenomenon by comprehending its components and their relationships. Since these relationships and interconnections are often complex, an OR approach may not capture the entire picture and the emergent behavior which can arise as a result of complexity. Rather, the system behavior is determined by precise cause-and-effect relationships (see, for instance, Ackoff 1962 and Keys 1991). Therefore, OR techniques are quantitative in nature and most applicable to well-defined problems at the tactical level shown on the left in Table 2.2.

Compared to OR, Systems Engineering is more qualitative and less analytical and is designed for tackling unstructured and complex problems (Sage 1992, Warfield 2006, Haimes 2016). As explained by Hipel et al. (2009a), Systems Engineering focuses on:

- quantitative and qualitative methods,
- strategic and tactical levels of decision-making,
- integration of technology, institutional perspective and value judgment,

- entire system including the components and their synergistic connections,
- holistic viewpoint,
- unstructured and complex problems, and
- single and multiple decision makers.

As pointed out in Sect. 2.3.1, the terminology of OR was coined by the British military who carried out "research" into the "operational" aspects of radar systems in 1938, since having a reliable defensive system against potential German bombing raids of the United Kingdom was of great concern to the British. The label Systems Engineering was first utilized in the Bell Telephone Laboratories in the 1940s (Schlager 1956) and this flexible approach to creative problem solving and design was quick to be adopted by many other organizations including NASA (National Aeronautics and Space Administration) in the United States of America and industry. The field of Systems Engineering continues to be developed at an expanding rate by both practitioners and researchers. Leading research papers on Systems Engineering can be found in journals such as the IEEE Transactions on Systems, Man, and Cybernetics: Systems; IEEE Systems Journal; as well as the journal Systems Engineering which is published by the International Council on Systems Engineering (INCOSE). In fact, INCOSE regularly releases reports on the latest advances in Systems Engineering. Departments of Systems Engineering exist in many universities situated in many nations around the globe. Systems Engineering groups exist in most large industrial organizations and many departments of Defence. Most professionals working in Systems Engineering and OR are fully aware of the developments in both of these fields and do not hesitate to utilize any relevant available methods from either area for addressing tough problems.

A classic book on Systems Engineering was written by one of its greatest pioneers, the late Andrew P. Sage, in 1992 (Sage 1992). Because Systems Engineering is such a dynamic and exciting field, an encompassing and universally adopted definition of Systems Engineering is difficult to find. In his highly innovative and informative approach to risk assessment, Haimes (2016) carries out risk studies within a Systems Engineering and multiple objective decision-making framework. A definition provided by K.W. Hipel is "Systems Engineering is an integrative and multidisciplinary approach to creative problem solving which takes into account stakeholders' value systems and satisfies important societal, environmental, economic and other criteria in order to enhance the decision-making process when designing, implementing, operating and maintaining a system or system of systems to meet societal needs in a fair, ethical and sustainable manner throughout the system's life cycle" (Hipel et al. 2007, 2009b).

Because thinking in terms of systems for problem solving is so widely accepted, publications regarding the systematic solving of challenging problems appear in journals in many disciplines. Basic systems-type methodologies that are closely related to Systems Engineering, and often thought of as being part of it, include control theory (Clarke et al. 1998), complex adaptive systems (Lansing 2009) and chaos theory (Thiétart and Forgues 1995).

Hipel et al. (2007) discussed the future of Systems Engineering in terms of application domains and research methods. As noted in the abstract of their paper "The methods [Systems Engineering] must be refined and expanded to meet the changing needs of the 21st century: from a system to a system-of-system; from a disciplinary outlook to a multidisciplinary outlook; from a mass production to a mass customization focus; from a steady state to a real-time perspective; and from an optimal to an adaptive approach." Accordingly, the important concepts of system of systems and adaptive management are explained in Sects. 2.4.1 and 2.4.2, respectively, with respect to their relevance to conflict resolution.

2.3.3 Decision Support Systems

A rich range of formal decision-making techniques have been developed in the fields of OR and Systems Engineering, as explained in Sects. 2.3.1 and 2.3.2, respectively. Moreover, a wide variety of game theory techniques are available for application purposes as pointed out in Sect. 2.2.2 and summarized in Fig. 2.1. The focus of this book is the Graph Model for Conflict Resolution (GMCR) for which many useful and powerful techniques are presented in detail as summarized in Sect. 1.3 and listed in the Table of Contents. Moreover, many extensions of GMCR are currently underway while others are planned, as discussed in Sects. 10.3.1 and 10.3.2, respectively.

To permit practitioners and researchers to conveniently apply mathematically-based techniques to physical-based, societal-founded, or combined systems problems, Decision Support Systems (DSSs) are needed. In this way, a user can focus on the insights gained from a rigorous investigation rather than on spending a significant amount of time programming an approach or a set of techniques, for solving the problem. Previously, DSSs were simply referenced to as "user-friendly" programs. As reflected in its title, the goal of a DSS is to aid or support decision-making by making known methodologies and associated data sets immediately available to a user, analyst or DM for applying to a problem of interest to him or her.

As emphasized by Hipel et al. (2008a), a formal model constitutes a representation of a system having a clearly defined mathematical structure. A properly designed model captures the key characteristics of the system or part of the system being studied to allow the system to be better understood so that informed decisions can be made regarding it. The mathematical analysis of a realistic model of a system can be highly effective in investigating the properties of the system and forecasting or simulating system behavior. When carrying out sensitivity analyses, the impacts of meaningful changes to one or more model parameters can be determined by comparing strategic findings before and after sensitivity analyses. Accordingly, one can obtain answers to "what-if" questions about the system. As noted above, a formal model, or collection of models, can be employed to rigorously examine physical, societal or hybrid systems.

A DSS is an easy-to-use computer package containing modeling and analytical capabilities, for one or more formal mathematical techniques. The DSS allows

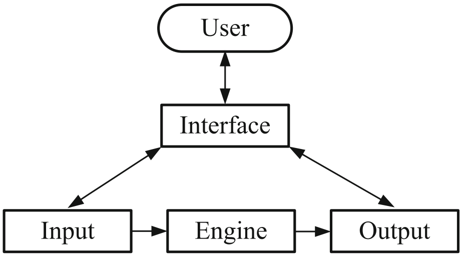

Fig. 2.2 Model-based decision support system for conflict resolution

practitioners and researchers to expeditiously create, revise, refine and analyze a model to support decisions. DSS technologies form one of the most important areas in the field of Information Technology (IT) which encompasses the development and application of computer software and hardware. In his landmark book on Decision Support Systems Engineering, Sage (1991) describes the main components of a DSS as being the Model-base Management System (MBMS) and Database Management System (DBMS) which are connected to a user via a Dialog Generation and Management System (DGMS). In fact, because of the great import of DSS engineering, in general, and in the field of conflict resolution, in particular, Chap. 10 is entirely devoted to the design of a DSS for applying to real-world conflict situations. A general discussion on DSSs is provided in Sect. 10.1.1 along with Fig. 10.1 depicting Sage's general design of DSS (Sage 1991). The rest of Chap. 10 focuses on DSSs for conflict resolution.

Figure 2.2 displays a simplified version of a model-based DSS for conflict resolution when using GMCR or another similar conflict model. The key input information required from the user via the interface (DGMS) is the decision makers (DMs), each DM's options or courses of actions and each DM's relative preferences among the feasible states or scenarios that could occur, as outlined in Sect. 1.2.2. What is particularly advantageous about GMCR is that a minimum amount of information is required by the user to build or calibrate a conflict model. The "grunt" work can be done by the DSS based on this information. The engine is used to carry out the stability calculations for each state from each DM's viewpoint according to a range of solution concepts describing potential human behaviors under conflict as discussed in Sect. 1.2.3. When a state is stable for all DMs according to a particular solution concept, it forms an equilibrium or potential resolution to the dispute under study. The engine can also determine outcomes for situations where DMs may cooperate with one another by forming coalitions. Follow-up analyses, such as the determination of the potential evolution of a conflict over time and various kinds of sensitivity analyses, are also carried out by the engine. As explained in Sect. 10.2.3, a highly efficient engine can be designed and constructed based on the matrix formulation of GMCR. Finally, the output from the DSS in Fig. 2.2 contains important strategic information calculated by the engine such as the potential resolutions and which resolutions can be reached from the current status quo situation.

A DSS furnishes a mechanism by which practitioners, researchers and society, in general, can take full advantage of advances in research in a given field of interest. From a researcher's perspective, a DSS is the means by which he or she can more directly contribute to the enhancements of society. Therefore, the final chapter of this book is entirely devoted to DSSs in conflict resolution. A person, who is trying to learn how moves and countermoves can take place in a conflict as DMs interact with one another, is encouraged to do some calculations by hand in order to fully understand the process and appreciate why GMCR is such a realistic decision technology. Keeping this in mind, a DSS is absolutely essential for GMCR to be widely adopted for helping to resolve conflicts ranging from the simple to the complex. Besides describing existing DSSs for GMCR in Sect. 10.1.2, a universal design for a DSS for GMCR is provided in Sect. 10.2. In this way, companies, government organizations, research teams and others can readily construct their own DSSs if the existing DSSs do not possess all of the capabilities that they require. Moreover, as pointed out in Sect. 10.3, new GMCR developments can be easily added to a properly built DSS.

2.4 Conflict Resolution in Responsible Governance

As explained in Sects. 2.2 and 2.3, a rich range of formal game theory and systems science tools, respectively, have been developed for providing advice to enhance the decision-making process. As pointed out in Sects. 2.3.1 and 2.3.2, many of these techniques were designed within the fields of Operations Research and Systems Engineering, respectively. Moreover, a variety of approaches to decision-making, such as value-focused thinking (Keeney 1992) and concentrating on the interests of the stakeholder (Fisher and Ury 1981, Fisher et al. 1991), have been proposed. Finally, general procedures for improving decision-making have been put forward in fields such as business administration, law, political science and sociology. The aforementioned and other procedures for making decisions can be employed within the general governance procedure outlined in this section.

Because humans live in a highly interconnected world in which the actions of one group of stakeholders can directly affect others, including the natural environment, a truly innovative systems thinking approach to governing society in a highly realistic and fair fashion is required. Accordingly, in the next section a System of Systems framework within which governance systems can be based is proposed. In Sect. 2.4.2, an integrative and adaptive paradigm for governance is described in which the value systems of the key interest groups are taken into account in a participatory way in order to reach desirable systems objectives such as resiliency, sustainability and fairness. The flowchart in Fig. 2.3 summarizes this realistic approach to responsible governance.

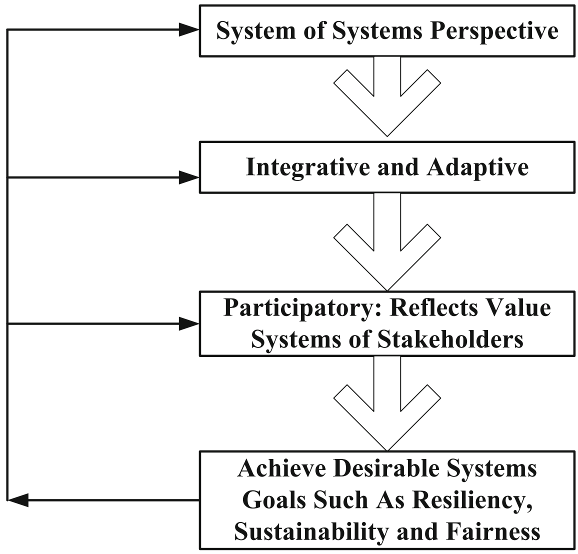

Fig. 2.3 Systems thinking in responsible governance

2.4.1 System of Systems

Multiple decision makers or participants, having their own objectives or value systems, inhabit the main sets of systems, existing on planet Earth (Hipel and Fang 2005). As depicted in Fig. 2.4, these key systems containing multiple stakeholders can be categorized into four main kinds of systems: environmental, societal, intelligent and integrated systems. Because each of these four groups contains many systems, it is referred to as a System of Systems (SoS). Illustrations of environmental systems are the atmospheric, geological, hydrological, zoological, botanical, and ecological systems. Examples of societal systems include agricultural, industrial, economic, political, governmental, infrastructure and urban systems. Within societal systems, creative people and organizations design, build and maintain intelligent systems, such as robotic, mechatronic and automated production systems for satisfying human demands and requirements. Integrated systems, such as individuals and software agents bidding for products over the internet using eBay, are formed by a combination of societal and intelligent systems. A modern commercial aircraft like a Boeing B787 Dreamliner or an Airbus A380, the world's largest passenger airliner, is another example of an integrated system since these planes can be flown automatically using specially designed intelligent systems or under the control of a pilot.

By referring to Fig. 2.5, one can envision how societal SoS and environmental SoS are interconnected (Hipel et al. 2009b). Notice on the left and right sides in this figure that the societal and environmental SoSs, respectively, consist of many systems. For instance, as can be seen on the right, the environmental SoS is composed of complex interrelated atmospheric, water, land and biological systems. As

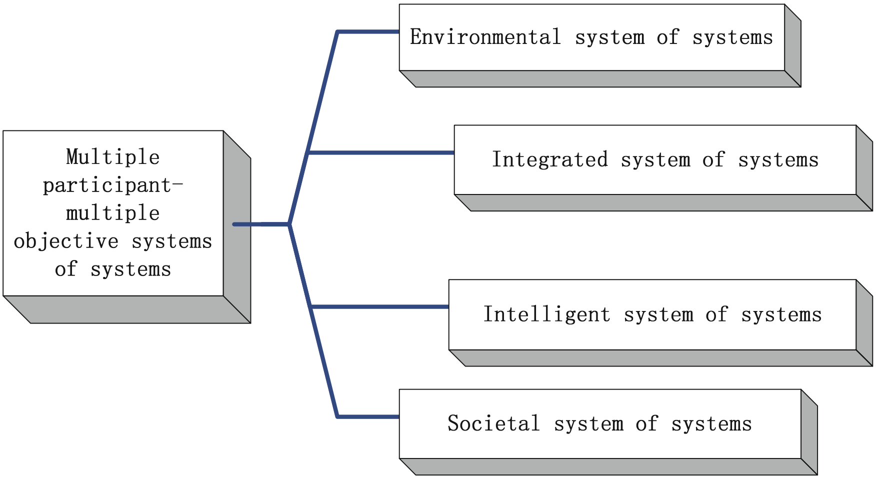

Fig. 2.4 Kinds of multiple participant-multiple objective systems of systems

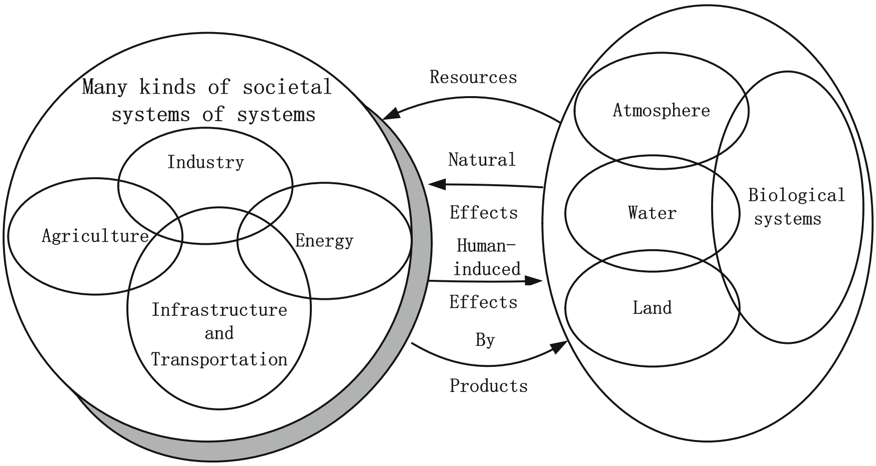

Fig. 2.5 Societal and environmental systems of systems

indicated by the arrow at the top linking these two sets of systems, societal SoS extract resources from the environmental SoS in order to function. For instance, the steel industry depends upon iron ore and energy sources from the environment to be able to operate. Unfortunately, by products from the range of activities occurring within the societal SoS are released into the environmental SoS. For example, carbon dioxide and other air pollutants are emitted from the smokestacks of steel plants which contribute to global warming and climate change while other pollutants are released into nearby bodies of water, thereby degrading water quality. As illustrated by the arrows in the middle, humans can affect both environmental and societal SoS while the natural world has a direct influence over societal SoS. Due to the large-scale release of greenhouse gases by many societal systems and associated land-use changes, humans are causing climate change which in turn degrades societal systems such as agriculture.

The concept of an SoS was developed to capture situations in which systems cooperate and interact with one another under certain circumstances but can also act as independent systems on other occasions. In their research, Sage and Biemer (2007) define an SoS as “a large-scale, complex system, involving a combination of technologies, humans, and organizations, and consisting of components that are systems themselves, achieving a unique end-state by providing synergistic capability from its component systems”. Research into the development of the idea of an SoS include contributions by Maier (1998), Sage and Cuppan (2001), Hipel and Fang (2005), Hipel et al. (2009b) and Jamshidi (2009). Based on earlier research by authors such as Maier (1998) and Sage and Cuppan (2001), the authors Sage and Biemer (2007) maintain that an SoS possesses a majority of the following characteristics: (1) operational independence of the individual systems; (2) managerial independence of the separate systems; (3) geographical distribution of the individual systems; (4) emergent behavior in which the SoS performs functions not possible by any of the individual systems on their own; (5) evolutionary development created by continuous interoperability relationships among systems; (6) self-organization; and (7) adaptation. By definition, an SoS constitutes a complex system, in which each individual system is autonomous because it may be evolving independently from other systems in the SoS.

Over the years, research has been carried out to model complex systems which includes contributions in fields like complex adaptive systems (Lansing 2009), chaos theory (Thiétart and Forgues 1995) and cybernetics (Wiener 1948). Contributions have been made on the design of SoS architecture for addressing a class of problems (see, for instance, Ge et al. (2013, 2014b)) including the employment of GMCR within this type of design (Ge et al. 2014a). An SoS approach has also been utilized for addressing quality control strategies for a complex product (Liu and Hipel 2012), risk management of extreme events (Bristow et al. 2012), global food security (Hipel et al. 2010), and water resources management (Hipel et al. 2011, 2013a). In order to model the decision making and physical systems characteristics of systems, one requires a broad range of flexible tools for utilization in these two realms, as explained by Hipel et al. (2008a, b). Sections 2.1 to 2.3 deal with formal decision-making tools with a focus on methods for employment in multiple participant-multiple objective decision-making. In fact, as mentioned in Sect. 1.1.2, the purpose of this text is to present the latest ideas in conflict resolution in order to address the strategic aspects of pressing real-world problems such as widespread pollution of the natural environment, climate change, international trade and regional wars.

As an explanation of how one would employ both decision-making and physical systems tools, consider the groundwater pollution problem described in Sect. 1.2. In this real-life dispute, by products from a chemical plant located in Elmira, Ontario, Canada, polluted the aquifer underlying this town with a carcinogen. The local government hired engineering consultants to determine the seriousness of the pollution and how far the plume containing the pollutant had spread. Bore holes were drilled at many locations to obtain samples of the groundwater and physical systems models expressed as differential equations were used to model the flow of the pollutant. In addition, methods for cleansing the aquifer and preventing further pollution were investigated. Within the societal aspects of this problem, the negotiations that took place in 1991 among the local government, company and the Ministry of the Environment in Ontario are formally modeled and analyzed in Sect. 4.5 to obtain strategic insights into how this problem could be resolved. As of late 2017, one quarter of a century after the carcinogen was discovered, the Elmira aquifer is continuing to be cleansed by pumping water from the underground aquifer and treating it before releasing it into a nearby stream, the company is treating its pollutants at the Elmira plant before discharging them, and the town of Elmira is receiving all of its water via a pipeline from the city of Waterloo situated 15 km to the south. This is clearly a very serious and expensive situation which would be much worse if a strategic settlement to rectify the situation had not been reached.

The Elmira groundwater contamination is an actual illustration of what is called a brownfield: land and groundwater which are contaminated by industrial activities. In reality, this is a widespread phenomenon in North America, Europe and the developing world. There are more than one-half million brownfields in the USA, 360,000 in Germany and 33,000 in Canada (NRTEE 2003, Hipel and BernathWalker 2011). The rapid industrialization of Asian nations is creating brownfields on a massive scale. Even though brownfields could be largely prevented by investing heavily in pollution control equipment during industrialization, nations prefer to first obtain wealth via industrialization in the quickest and cheapest way possible and to clean up the brownfields later. This, of course, is much more expensive in the long term and some of the damage may be irreversible. Enhanced decision-making methodologies such as the game theory techniques presented in this book may assist in making more informed decisions since they directly take into account both the long and short term values of the various decision makers.

Today, the nations of the world are knowingly dumping massive amounts of greenhouse gases (GHG) into the "atmospheric commons" even though they are aware that this short-term behavior is causing temperatures to significantly rise over time with increasingly devastating consequences. In other words, the countries are playing the self-interest version of Prisoner's Dilemma, rather than the long-sighted version in which the nations cooperate and thereby greatly reduce greenhouse gas releases starting now so they will all benefit more in the long run. The main uncertainty that currently remains is whether the climate system has already reached the point of no-return in which global warming will be irreversible no matter what society does. An important fact to mention is that the physical systems and other related solutions to this global warming problem are already known. In particular, nuclear power plants, renewable energy, energy efficiency and life-style changes are well recognized solutions which can be expeditiously implemented to greatly reduce the use of fossil fuels. Coal fired-plants for generating electricity can be quickly converted to gas-fired plants to reduce carbon dioxide emissions by 50% in the short term and subsequently close down in the medium term when they can be replaced by cleaner energy sources. Where society has failed up to the present time is to solve the societal and strategic aspects of climate change, especially with respect to reaching meaningful negotiated agreements at the international, national, provincial and local levels to significantly cut back on greenhouse gas emissions.

Within Canada, Magna International Inc., a large car parts manufacturing corporation based in Ontario, commissioned the Council of Canadian Academies (CCA) to put together an Expert Panel to investigate the latest evidence regarding energy use and climate change and what can be done to reduce GHG emissions. Subsequently, one year later, the Expert Panel on Energy Use and Climate Change, consisting of an interdisciplinary group of eight people and co-chaired by Keith W. Hipel and Paul R. Portney, completed its report entitled "Technology and Policy Options for a Low Emission Energy System in Canada", which was officially released by the CCA on October 27, 2015 (CCA 2015). The three key findings of the Expert Panel based on the existing evidence are:

- Technology options are available now to move to a low-emission energy system. In fact, Canada could reduce its GHG emissions from 60% to 90% at manageable cost.
- The electricity supply system should be decarbonized by replacing coal and gas-fired electricity generation plants by non-GHG energy generation systems such as renewable, nuclear and hydro.
- Economy-wide policies are needed to meet stringent GHG cutback requirements, but flexible in the sense that different measures could be taken to accomplish this. For instance, the Province of British Columbia already has a carbon tax which has worked extremely well whereas Ontario and Quebec have elected to use a cap and trade system.

Within Canada, negotiations involving the Federal Government, ten Canadian Provinces and three Territories are needed to come up with a harmonized set of policies and associated physical systems solutions to significantly reduce GHG releases. Moreover, since an agreement among the nations of the world reached in Paris on December 11, 2015 has no mandatory or legal requirements for countries to greatly reduce their GHG emissions, intense negotiations will still have to take place to accomplish this. Fortunately, the countries did state that they would not like temperature increases to go beyond 1.5 °C, which in turn means drastic GHG emission cutbacks are necessary. All of this indicates that comprehensive negotiation tools could prove to be extremely useful for reaching binding and lasting agreements. However, the election of American President Donald Trump on November 8, 2016, meant that the United States may weaken or withdraw its commitments to reducing its GHG emissions put forward in Paris. In fact, in June 2017, the US announced its intention to withdraw from the Paris Accord, for which the earliest effective date of US withdrawal is November 2020. The game theoretic procedures presented in this book are designed to assist with reaching agreements among stakeholders having conflicting objectives in order to resolve tough SoS problems such as climate change, as exemplified by Bernath Walker and Hipel (2017) and He et al. (2017).

Conflict resolution tools mentioned in Sect. 2.2, economics, and ideas from the social sciences can be employed within a responsible governance system to solve climate change and many other tough decision problems facing society. A governance system includes policies, agreements, laws, regulations, compliance methods, monitoring, institutions and management. The key aspects needed in governance systems are discussed next and also noted in Fig. 2.3.

2.4.2 Integrative and Adaptive Management

Because water resources engineers and managers must deal with both the physical aspects of water management as well as the societal components, they are global leaders on how to design effective governance systems. Moreover, they were one of the first groups of professionals outside of the military to adopt, enhance and expand operations research and systems engineering tools for solving challenging SoS problems. In addition, they have developed a range of decision support systems (DSSs) for implementing both the physical and societal systems parts of SoS problem solving to allow these tools to be utilized by both practitioners and researchers (Hipel et al. 2008a, b).

Integrative and adaptive management constitute two key interrelated concepts needed for achieving effective water governance within an SoS structure. As explained in "A Handbook for Integrated Water Resources Management in Basins" published in 2009 by the Global Water Partnership (GWP) and International Network of Basin Organizations (INBO) (GWP and INBO 2009), "The integrated water resources management approach helps to manage and develop water resources in a sustainable and balanced way, taking account of social, economic and environmental interests. It recognizes the many different and competing interest groups, the sectors that use and abuse water, and the needs of the environment." This systems thinking approach to water resources management directly states that many interconnected factors must be taken into account and that the value systems of competing stakeholders and environmental requirements must be entertained. Additionally, because of the physical reality that a watershed controls the flow of water, water management practices must be implemented at the basin level in consonance with policy, laws and regulations at the local, regional, provincial or state, national and international levels. For instance, the International Joint Commission (IJC) (IJC 2009) recommends an integrated approach to river basin management for basins that are intersected by the Canada-US border. The IJC is an independent binational body having investigative, regulatory and adjudicative roles for implementing the 1909 Boundary Waters Treaty between Canada and the USA for impartially addressing water and environmental problems between the two nations.

In addition to being integrative, water and other types of governance must be adaptive to be capable of handling the largely unpredictable behavior of environmental and societal SoSs caused by their intrinsic complexity, uncertainty and interconnectedness. As a result of this unpredictability, one does not know in advance how well a given policy is going to function for appropriately tackling both anticipated and unexpected events. Within the concept of passive adaptive management, one utilizes new knowledge garnered by monitoring and experience to iteratively refine plans to improve existing management approaches and related decision-making. When practicing active adaptive management, strategies are purposefully changed in order to scientifically test new hypotheses, and thereby learn by experimentation to determine the best management strategy. Therefore, adaptive management is popularly referred to as "learning by doing". The clever idea of adaptive management was originally put forward by Holling (1978) and other scientists as a consequence of investigating resiliency theories of ecological systems, and since that time a rich body of literature has amassed such as contributions by Walters (1986), Gunderson and Holling (2002), Noble (2004), NRC (2004), AWRA (2006, 2009), Gunderson and Light (2006), and Williams and Jackson (2007).

In their research, Hipel et al. (2008b, 2009b) recommend that adaptive integrative management be conducted within a SoS framework in combination with the employment of formal decision-making tools, from operations research, systems engineering and other systems science fields (see Sect. 2.3), as well as ideas from the social sciences and humanities. Additionally, any policy or agreement should reflect the value systems of the stakeholders it serves and contain a dispute resolution mechanism that guides disputants in a positive direction towards a win/win resolution. This can be strengthened in practice by adopting a participatory approach to involving stakeholders in the practice of responsible governance and making the various decision technologies available as DSSs.

Throughout this book, case studies involving actual disputes in a range of different fields are employed to demonstrate how the various related conflict resolution methods can be conveniently applied in practice to better understand problems and gain strategic insights for improving decision-making. However, the reader is encouraged to keep in mind that conflict resolution is usually employed in conjunction with other societal and physical systems tools within an integrative and adaptive approach to governance embedded in an SoS framework.

2.5 Important Ideas

The decisions that you make determine your destiny. Therefore, you want to make the most informed possible decision to help you reach your goals, keeping in mind that in decisions involving interactions with others, you must understand their values and the effects they can have upon you depending on which actions they select. In a given conflict situation, you may wish to consider joining a coalition to ascertain if you can do even better via meaningful cooperation with others to achieve a win/win resolution.

The Graph Model for Conflict Resolution (GMCR) has a key role to play in tackling tough decision problems involving multiple participants each of whom possesses his or her own values, objectives or preferences. Among an array of available game theoretical methods described in Sect. 2.2 and portrayed in Fig. 2.1, GMCR is especially effective in addressing actual complex conflicts in almost any field ranging from very simple ones to large disputes. In fact, GMCR constitutes a unique and relatively new formal decision-making method which nicely complements the rich range of decision tools developed in fields such as Operations Research (Sect. 2.3.1), Systems Engineering (Sect. 2.3.2) and elsewhere. When implemented as a Decision Support System (Sect. 2.3.3 and Chap. 10), GMCR constitutes a truly powerful decision technology for formally studying real-world conflicts. When utilized within a system of systems engineering perspective (Sect. 2.4.1) to integrative and adaptive management in a participatory fashion (Sect. 2.4.2), GMCR can be utilized as an important and complementary methodology for effectively carrying out responsible governance.

2.6 Problems

2.6.1 In Sect. 2.2.2 and Fig. 2.1, game theory methods are classified and put into perspective. In the right branch in Fig. 2.1, agent-based models are listed as a set of techniques. Find a journal paper or textbook on agent-based modeling and briefly explain the basic idea underlying it and how it is used in practice. Outline how it could be used in policy design and analysis.

2.6.2 A game theoretical method listed in the right branch in Fig. 2.1 is extensive form. By referring to a journal paper or book, outline how extensive form works. According to Chap. 4 in the book by Fang et al. (1993) qualitatively explain how the Graph Model for Conflict Resolution and extensive form are connected. What is a key drawback of extensive form?

2.6.3 Drama Theory is listed in the left branch of Fig. 2.1. Locate a journal paper or book dealing with Drama Theory to use as a basis for successfully outlining how Drama Theory works.

2.6.4 The conflict analysis approach of Fraser and Hipel (1979, 1984) is part of the left branch in Fig. 2.1. Describe three improvements to Conflict Analysis which are embedded in the Graph Model for Conflict Resolution. Be sure to supply references to the literature to support the enhancements that you mention.

2.6.5 As noted in Sect. 2.3.1, Operations Research (OR) was founded by the British military just prior to the outbreak of WWII in Europe. Many classified documents regarding the development and employment of OR during the war were released 50 years after the war ended. Select an interesting paper describing the successful utilization of OR during the war and outline the points in the paper that you personally found to be of interest to you.

2.6.6 How did the American fleet in the Pacific Ocean during WWII use a "soft" systems approach to encryption to communicate among their ships, especially their lethal aircraft carriers. (Hint: Find a reference involving the famous "code talkers".)

2.6.7 One of the most famous code breakers working at Bletchley Park northwest of London during WWII to break the German codes was Dr. William Tutte. What great feat did he accomplish and at which university did he help found a famous Faculty of Mathematics after WWII?

2.6.8 Locate a paper in the IEEE Transactions on Systems, Man and Cybernetics: Systems which deals with system of systems engineering. Outline the main contributions in the paper and explain why a system of systems engineering approach was useful and insightful in dealing with the problems addressed in the paper.

2.6.9 The International Council on Systems Engineering (INCOSE) is a strong proponent of the system of system (SoS) engineering approach and publishes the journal called Systems Engineering. Select an SoS engineering report published by INCOSE or else a journal article dealing with this topic. Summarize the key contributions of the article and explain why an SoS engineering approach was highly effective for solving the problem studied in the article.

2.6.10 Why is the Graph Model for Conflict Resolution an indispensable approach for using within a system of systems engineering approach to problem solving and creative decision-making?

2.6.11 Select a reference on decision support systems (DSSs) that is of high interest to you. Based on this reference, outline the basic design of a DSS and why DSSs are essential for employment in real-world decision-making.

2.6.12 Most of the key ideas in integrative and adaptive management addressed in Sect. 2.4.2 came from the field of water resources. Choose a key journal paper or book from the water resources literature which deals with integrated and adaptive water resources management in a participatory fashion. Outline the key contents of this paper and explain why conflict resolution has a key role to play in this insightful approach to management.

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