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NEGOTIATION AND MEDIATION IN CONFLICTS I: THE ROLE OF MATHEMATICAL APPROACHES AND METHODS

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NEGOTIATION AND MEDIATION IN CONFLICTS
I: THE ROLE OF MATHEMATICAL APPROACHES AND METHODS

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Abstract. There are many possible approaches to the analysis of conflict situations and ways of developing mediation or negotiation procedures. In general, we can distinguish between *socio-political approaches*, procedures for mediation and negotiation which have developed historically through political experience, and *systems-analytical, mathematical approaches*, which rely on various branches of decision and game theory or on computerized simulation or gaming models. While the socio-political approaches must remain the basis of any analysis of conflict situations, they can usefully be supplemented by more-formalized approaches; both approaches, when used separately, have their limitations.

This paper, after a short review of existing systems-analytical and mathematical approaches, proposes new concepts and methods for the mathematical analysis of conflict processes. The proposed approach attempts to bridge the gap between simulation gaming models and experiments and more formal game-theoretical analysis by taking certain ideas from interactive decision supported gaming, assuming that the players have multiple objectives that they wish to satisfice (not optimize), and introducing special mediation procedures as an element of decision support during the game. The mathematical concepts used are the selection of satisficing game equilibria, the definition of constructive and destructive behavior (on the part of the players), and a formalization of conflict escalation and de-escalation processes.

Keywords. Game theory; gaming; conflict analysis; negotiation theory; mediation; interactive decision support; satisficing.

INTRODUCTION

The study of conflicts and the possible role of negotiation and mediation has a long tradition in the political and social sciences (see, e.g., Machiavelli, 1515). The need for a better understanding of the processes involved has become even more urgent since the development of nuclear weapons. As a result, the study of negotiations has recently become the subject of very intensive research via a number of disciplines. For example, a project at Harvard University brings together lawyers, political scientists, economists, mathematical game theorists and decision theorists as well as representatives of other disciplines (see, e.g., Fisher and Ury, 1981; Raiffa, 1982). We can divide these disciplinary approaches into two broad categories: *socio-political approaches* and *systems-analytical, mathematical approaches*.

Traditionally, the study of negotiation and mediation during conflicts has been the domain of political and historical scientists, diplomats, psychologists and sociologists. These socio-political approaches will probably remain the basis of all future analyses of conflict, negotiation and mediation; without a deep understanding of the underlying socio-political processes, no formalized characterization of any decision process can ever be relevant (see, e.g., Wierzbicki, 1983). This does not mean, however, that systems-analytical or even mathematical formalization cannot increase our understanding of conflict processes. As in many other areas of scientific endeavor, mathematical formalization can help, first, in checking the consistency of basic concepts and images. When the underlying concepts are clear, relevant and focused on essentials, mathematical formalization can also help us to deal with complexity by producing frameworks for possible mathematical models. Finally, given these concepts and frameworks, computerized models can be built and used for various purposes: for overcoming complexity, for educating and assisting decision makers in particular aspects of a problem, as a tool for stimulating interaction between the parties involved in a dispute, and so on (see, e.g., Sebenius, 1981).

The systems-analytical and mathematical approaches have produced a large variety of concepts and tools which could be useful in studying conflict, negotiations and mediation. One of the earliest mathematical descriptions of armed conflict (a "battle model") was produced by Lanchester (1916); such battle models, developed further by Richardson (1960), Rappaport (1957), and recently by Avenhaus and Fichtner (1983), can also suggest initial conditions that would reduce the likelihood of war and could thus be helpful in negotiations.

Since the early days of game theory (see von Neumann and Morgenstern, 1944) it has been hoped that game-theoretical analysis might help to increase our understanding of conflicts. However, while game theory has formalized many essential concepts in this field, its underlying assumptions--namely, that players behave in such a way as to maximize their own utility function--may still limit its potential usefulness. In particular, formal models of bargaining (see, e.g., Roth, 1979) are not necessarily supported by experimental studies of bargaining behavior (Roth, 1983); the paradox of short-sighted rational behavior exemplified by the so-called 'prisoner's dilemma', which was solved long ago by anthropologists studying primitive forms of barter, has only recently found more formal resolution in evolutionary game theory (Maynard-Smith, 1977; Axelrod, 1983; Hofstadter, 1983).

The more application-oriented mathematical approaches often rely on less sophisticated but more reliable tools. In particular, decision-tree analysis is frequently used to examine crisis situations. Dynamic simulation and gaming models also have a wide range of applications (see, e.g., Stahl, 1983). However, despite their many excellent features, gaming simulation models and experiments do not give sufficient insight into the possible conflict escalation or de-escalation processes arising from the properties of the game. Although escalation and de-escalation have been observed in many gaming experiments, there are as yet no analytical tools to help us understand these empirical observations. The need for further research on such tools is therefore vital.

This paper suggests a number of new concepts and methods for the mathematical analysis of conflict processes. The basic assumptions of this approach are as follows:

1. While it is recognized that gaming simulation models and experiments are already very successful in conflict analysis, we attempt to extend these gaming simulation techniques by providing *decision support* based on concepts and methods from game theory and multiobjective optimization. This leads to a new class of gaming techniques which we call *interactive decision-supported gaming*.

2. Many gaming experiments show that the players do not think in terms of one utility function, but try to balance several goals or objectives. Also, players do not necessarily behave as maximizers, often exhibiting *satisficing* behavior instead (see, e.g., Simon, 1969). Thus, the game-theoretical concepts and methods used in decision support are modified to take this *multiobjective and satisficing behavior* into account.

3. Interactive decision-supported gaming as described above can be used either as a means of teaching players about the *process of conflict escalation*, or in conjunction with formalized *mediation procedures* to illustrate how *conflict de-escalation* can be achieved.

A COASTAL WATERS AND OPEN SEA FISHING GAME

As an illustration, let us consider a fishing game developed by M. Staley and C. Walters at IIASA.[1] For simplicity, we shall limit the problem to only two countries (1 and 2); they can fish either in their own coastal waters or in the open sea. The fish being caught is assumed to spawn in the rivers of a given country (like salmon); thus, the fish return from the open sea to these rivers each year and it is reasonable to refer to the stock of fish originating from each country. Suppose the stocks in a given year are x_i, $i = 1,2$; the size of the native fleet fishing in its own coastal waters is c_i (fishing in the other country's coastal waters is prohibited); the size of each fleet fishing in the open sea is s_i. Then the catch of each country can be approximated by

$$z_i = \left(\frac{s_i}{s_i+s_{\hat{i}}}\right) \{1 - \exp[-\alpha(s_i+s_{\hat{i}})]\}(x_i+x_{\hat{i}}) + \exp[-\alpha(s_i+s_{\hat{i}})][1-\exp(-\alpha c_i)]x_i \qquad (1)$$

where the first term describes the catch in the open sea, the second the catch in coastal waters, $\hat{i}$ denotes the variables of the

[1] Private communication; although many experiments have been performed with this game, a full description has not yet been published.

"other" country, and α is a parameter. Like the stock, the catch can be measured directly in monetary units, and should be compared with the cost of maintaining the fleet, $p(c_i+s_i)$. However, this analysis considers only short-term benefits and costs. The long-term benefits can be characterized by the stocks expected in the following year:

$$x_{i,t+1} = x_{i,t}\{\exp[-\alpha(s_i+s_{\bar{i}}+c_i)]\} \times$$
$$\times\ r(x_{i,t}\exp[-\alpha(s_i+s_{\bar{i}}+c_i)]) \qquad (2)$$

where r(.) is a reproduction rate coefficient. Typically, the expression (2) is highly nonlinear and random; if the stocks are already strongly depleted, however, we can approximate (2) by assuming $r(.) = r =$ constant. Taking into account both short- and long-term benefits and costs, the payoff functions for players representing both countries are

$$q_i = z_i - p(c_i+s_i) + x_{i,t+1} \qquad (3)$$

with z_i evaluated at $x_i = x_{i,t}$. The actual gaming model used in practice may be considerably more complicated than the basic framework outlined above, including dynamic simulation over several years, the possibility of increasing the size of the fleet through investment, the use of hatcheries, etc. A model of this type has been used in intensive experimental gaming, with some interesting results. Three clusters of outcomes seem to emerge from the gaming experiments. One type of result (called *cooperative*) arises when the players agree tacitly not to fish too extensively; this results in high payoffs q_i and stocks $x_{i,t+1}$ at the end of the game. The second type of result can be called *dominated*--this occurs when one player makes much higher catches z_i and receives much higher payoffs q_i than the other. The third type can be called *destructive*; in this case both players use very large fleets, drastically reducing both payoffs and future stocks of fish. Moreover, the players typically reduce the size of the fleet fishing in their coastal waters c_i and increase their sea-going fleet s_i . Results of these three types have also been observed in actual fishing disputes between neighboring countries.

The question that we address here is whether game-theoretical analysis can help us to understand gaming results such as these, and to explain the behavior of players as the conflict develops. The present answer is a qualified yes, where the qualification arises from the limitations of classical tools. Figure 1 represents the *image of the game*[2] (the set of attainable payoffs), calculated making the simple assumptions $x_1=x_2=5$, $\alpha=p=1$, $r(.)=r=3$, $s_i+c_i\in[0;5]$. By a classical game analysis, we can easily show that $c_i=0$ is optimal for both players and that the game has several noncooperative (Nash) equilibria (Nash, 1950, 1953) denoted in Fig. 1 by N_0, N_1, N_2; obviously, N_0 is the dominant Nash equilibrium and the single Pareto point for the game.

Thus, how could it happen that players leave the point N_0 to produce results clustered in regions (I), (II_1, II_2), and (III) in Fig. 1? How can we explain the process of conflict escalation that typically occurs in experimental gaming, and may be illustrated by the sequence of points $(A_0)\to(A_1$ or $A_2)\to A_3\to(A_4$ or $A_5)\to A_6$ in Fig. 1?

To explain this, we must assume that the players are motivated by something more complicated than simple payoff maximization. First, we observe that the point N_0 corresponds to zero catches, $z_1=z_2=0$. However, a positive catch is necessary to keep up the fish supply (and the cash flow); hence, both players must have more than one objective, keeping an eye on final payoffs but concentrating on fish catches.

We could now follow the classical approach and assume that the players have utility or value functions $u_1(q_1,z_1)$ and $u_2(q_2,z_2)$ that result in an equilibrium, say, at the point A_0 . However, the utility function approach has several drawbacks in conflict analysis. First, any information on utility functions has crucial strategic value and is usually carefully protected; therefore, we cannot hope that full and precise information on utility functions will be available for incorporation into a gaming model. Second, a process of conflict escalation or de-escalation usually involves modifications to the utility functions, since experimentally observed utility functions are typically not context-free (see, e.g., Tversky, 1972). Third, real players usually do not think in terms of utility maximization, and even if assured that such information would be treated as confidential, would find it difficult to communicate their utility functions to a third party (computer or mediator).

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[2] A detailed mathematical analysis is given in the second part of this paper: "Satisficing Selections of Game Equilibria".

Therefore, we adopt in this paper another approach that is both flexible and pragmatic and, at the same time, opens new opportunities for conflict analysis and for communication between players and model. We assume that players either actually think in terms of *aspiration levels* (Wierzbicki, 1982) for their various objectives, or can be taught to do so. Moreover, we assume that these aspiration levels can be adaptively modified during a gaming exercise. We suppose that the process of aspiration level formation occurs in players' minds, but that players might be induced (by assurances of confidentiality) to communicate their current aspiration levels to the computer in order to receive, in return, some decision or mediation support.

To put these concepts into practice, we calculate sets of equilibria such that the outcomes are Pareto for the objectives z_i, q_i of each player but noncooperative between players. These sets are rather large (see sets NP_1, NP_2 in Fig. 2), but exclude some outcomes (sets U_1, U_2) that are unstable to the interests and decisions of either of the players (observe that the sets of typical outcomes shown in Fig. 1 lie almost completely within NP_1, NP_2). If we add to the image of the game the lines of constant outcomes z_i for each player, as in Fig. 2, we can explain the process of conflict escalation through the phenomenon of *inflated aspirations*. By inflated aspirations we mean aspirations that exceed the limits imposed (for example) by physical, biological, and environmental factors: the role of the model is to represent these natural limits and to help the players to learn about them.

Let us now suppose that the game is played repetitively (representing fishing activity over many years) and that both players initially make decisions that lead to outcome A_0, corresponding to catches $z_1=z_2\approx 1$ and payoffs $q_1=q_2\approx 13$. If the players behave cooperatively, they can stay close to $N_0=P$ and gain high future payoffs. However, suppose player 1 wants to expand and decides to increase his catch to $z_1=6$ (point A_1) in order to increase his short-term returns and to finance new investment in his fishing fleet. If the other player does not reciprocate, then player 1 succeeds in his goals and obtains a dominant position in future rounds. If player 2 reciprocates, however, the catch of the first player decreases to $z_1=z_2\approx 4$ (point A_3). However, player 1 may have already made large investment commitments and must increase his catch; thus, he might increase his fleet and hence his catch still further (point A_4). If the other player reciprocates, the outcome would be the worst Nash equilibrium (N_2), with catches $z_1=z_2\approx 5$ and almost no fish remaining for the following year. This Nash equilibrium is not very robust to multiobjective behavior with inflated aspirations; further escalation can easily lead to the attrition point A_6.

Although one could learn much from the above simple example, and draw many analogies (for example, to the arms race), we shall conclude the analysis with the observation that the behavior of players in such a game can be explained, first, by their multiple objectives, and second, by their inflated aspirations. If they learn quickly to revise their aspiration levels downwards, they can survive; however, if they maintain their inflated aspirations only slightly too long, conflict can escalate very speedily.

This lesson can be taught when playing simulation games; however, we then need to concentrate the attention of the players on their aspirations. Ideally, the decision support system should produce a full image of the game, such as that shown in Fig. 2. However, this might require excessive computer time for more complicated games. Failing this, the decision support system could compute the strategies that each player should adopt to come close to some explicitly stated aspiration levels of their own, making certain assumptions concerning the aspiration levels of the other players. In order to achieve this, we must introduce some principles for *selecting game equilibria* that relate to the concept of aspiration levels and thus to some form of *satisficing* behavior. Although these concepts apply to multiobjective games, it is simpler to interpret them graphically for a single-objective game, provided its set of noncooperative equilibria is large. (Sets of multiobjective noncooperative equilibria are generally large, giving the players a wider choice of possible outcomes in which they are guided by their aspiration levels.)

A "FISHING IN NEIGHBORS' COASTAL WATERS" GAME

We consider here a simplified example of a game that has only historical significance, because most countries now refrain from fishing in each other's coastal waters. Two countries, $i=1,2$, fish in each other's, $\bar{i}=2,1$, coastal waters. Each country can decide how much to take from foreign waters (we denote this decision by x_1^i) and what restrictions to impose on foreign boats

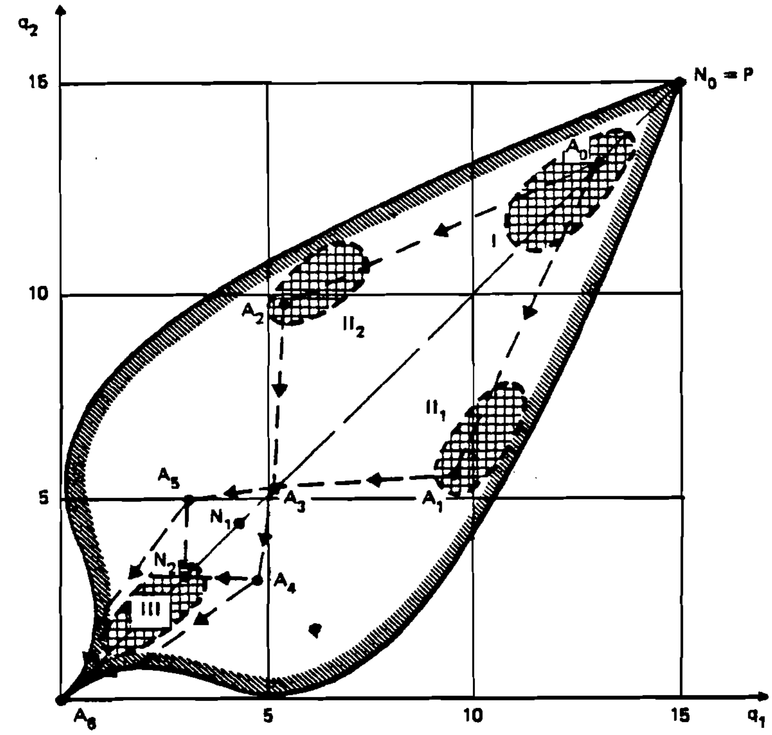

Fig. 1. Image of an open sea fishing game. N_0, N_1, N_2 are noncooperative Nash equilibria, with $N_0 > N_1 > N_2$. I, II_1, II_2, III are approximations of typical sets of experimental outcomes. The series of moves $A_0 \rightarrow (A_1,\ A_2) \rightarrow A_3 \rightarrow (A_4,\ A_5) \rightarrow$ either N_2 or A_6 represents a conflict escalation process.

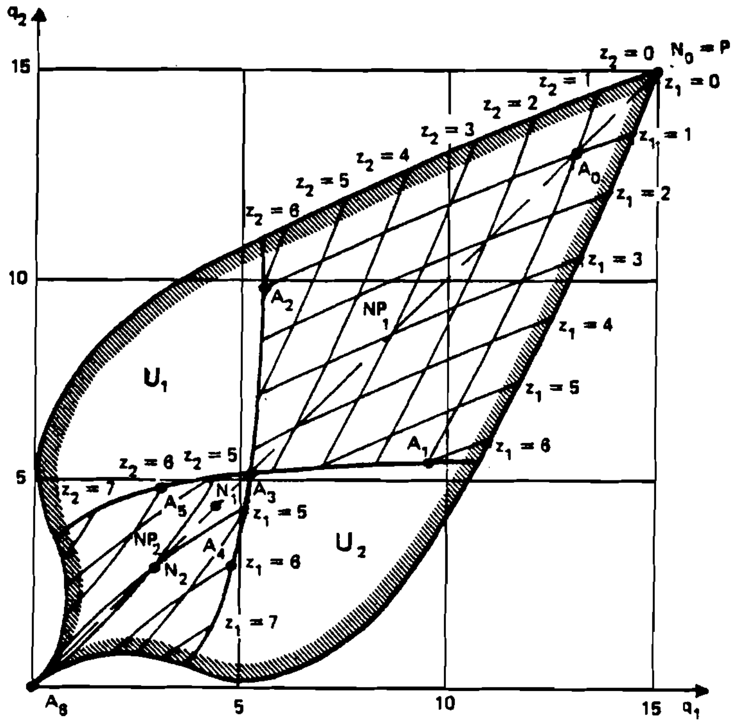

Fig. 2. Full image of an open sea fishing game. N_0, N_1, N_2 are economic Nash equilibria; NP_1, NP_2 are sets of multiobjective Nash-Pareto equilibria; U_1, U_2 are sets of unstable outcomes. The series of moves $(A_1,\ A_2) \rightarrow A_3 \rightarrow (A_4,\ A_5) \rightarrow A_6$ represents a process of conflict escalation in which both players insist on fish catches $z_1 = 6$, $z_2 = 6$.

fishing in their waters (x_2^i); if the restrictions are disobeyed, both the offending country and the enforcing country incur additional costs. The payoff functions have the form:

$$q_i = f_i(x) = a_{i0} - a_{i1}x_1^{\hat{i}} + a_{i2}x_1^{i} - a_{i3}x_2^{\hat{i}} - a_{i4}(x_1^{i} + x_2^{\hat{i}} - \bar{x}^{\hat{i}})_+ - a_{i5}(x_1^{\hat{i}} + x_2^{i} - \bar{x}^{i})_+ \qquad (4)$$

where $(.)_+$ denotes taking the positive part, $a_{i0} - a_{i1}x_1^{\hat{i}}$ represents the net gain from the country's own waters (diminishing with increased fishing by outsiders), $a_{i2}x_1^{i} - a_{i3}x_2^{\hat{i}}$ represents the net gain from fishing in foreign waters (diminishing with increased restrictions), the last but one term represents the penalties for disobeying the restrictions of other countries and the last term the cost of enforcing its own restrictions. All decision variables, $x = (x_1^1, x_2^1, x_1^2, x_2^2) \in \mathbb{R}^4$ are constrained by $0 \leq x_j^i \leq \tilde{x}_j^i$.

This example serves to illustrate the mathematical and computational difficulties involved in determining sets of noncooperative equilibria;[3] however, these difficulties can be overcome and the image of the game, together with the set of Nash equilibria N_q, is shown in Fig. 3 for $a_{i0}=2.4$, $a_{i1}=6$, $a_{i2}=1$, $a_{i3}=2$, $a_{i4}=a_{i5}=4$, $\tilde{x}_j^i=0.8$, $j,i=1,2$. The Nash equilibria in this case have a rather simple interpretation: they correspond to the situation in which each country strictly obeys the restrictions of others. The Nash outcomes of this game are not Pareto outcomes; Pareto outcomes correspond to dropping restrictions entirely, or, at the point P_0, to the complete cessation of fishing in foreign waters. It is interesting to note that the point P_0 has finally been reached through the historical development of fishing practices.[4]

[3] This is equivalent to a min-max problem involving nondifferentiable functions that do not remain convex after the first maximization; see Part II of this paper.

[4] The point P_0 is not a Nash equilibrium for the one-period game, but can be shown to be an evolutionary stable equilibrium for a repetitive game. Thus we might hope that all 'prisoner's dilemmas', characterized by the difference of Nash and Pareto points, will finally be resolved in an evolutionary way (see also Hofstadter, 1983). In the case of the arms race, however, it is but small consolation for us to hope that other races in the universe might learn from our own evolutionary mistakes.

However, in the course of this historical process there have also been cases in which the worst point SD has been reached. This point is attained when both countries decide to fish as much as possible in each other's waters and, at the same time, to impose and try to enforce extreme restrictions on anybody fishing in their own waters--a case of open fishing war. There are concepts in game theory that explain the development of this situation, albeit in a rather simplified fashion.

An old concept in game theory is that of a Stackelberg equilibrium (see, e.g., Aubin, 1979). Suppose one of the players has enough information to compute the responses of the other players (who wish to maximize their own payoffs) to any of his own decisions. If the responses are nonunique, he can assume, to be on the safe side, that only those that contribute least to his own payoff will be chosen. These response functions uniquely determine the dependence of his own payoff on his own decisions, taking into account the responses of others, and his own payoff can then be maximized. A player who makes his decisions in such a way is called the (Stackelberg) leader; if other players respond as predicted, they are called (Stackelberg) followers; the resulting outcome is called the Stackelberg equilibrium (this is one of the Nash equilibria, chosen through the (safe) maximization of the payoff of the leader). In the example considered here, if the first player wants to be the leader, he concludes that by sending the largest possible fleet to fish in his opponent's waters and by imposing the severest possible restrictions on intruders into his own waters, he might force the other player to "follow" him. Indeed, since both enforcing restrictions and violating them are very costly in this game, the second player might maximize his own short-term interests by imposing only the minimal restrictions compatible with the fleet of the leader (or even dropping restrictions altogether--but the leader cannot count on this) and sending only the smallest possible fleet to the leader's waters.

This interpretation shows, however, that the reasoning of the Stackelberg leader is completely unrealistic if no additional legal or institutional circumstances force the other player to become a follower. A sovereign country would not accept the follower's role and would denounce as hypocritical the explanations of the aspiring leader that the follower's role is logical from the point of view of economic payoffs. In the example considered here, the second player might well respond by repeating the actions of the first--this would result in a so-called Stackelberg disequilibrium (a situation in which both players try to become the leader) and corresponds to an open fishing war in our example.

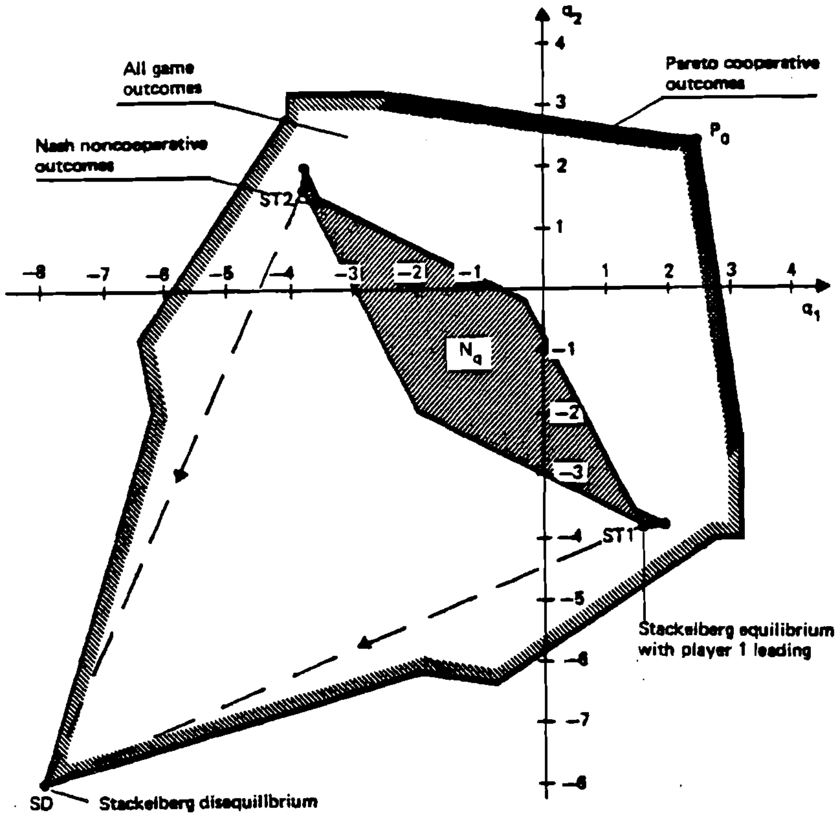

Fig. 3. Image of the game: $q_1 = f_1(x) = 2.4-6x_1^2+x_1^1-2x_2^2-4[(x_1^1+x_2^2-1)_+ + (x_1^2+x_2^1-1)_+]$

$q_2 = f_2(x) = 2.4-6x_1^1+x_1^2-2x_2^1-4[(x_1^1+x_2^2-1)_+ + (x_1^2+x_2^1-1)_+]$

$x \in X = \{x \in \mathbb{R}^4 \ : \ 0 \leq x_j^i \leq 0.8\}$.

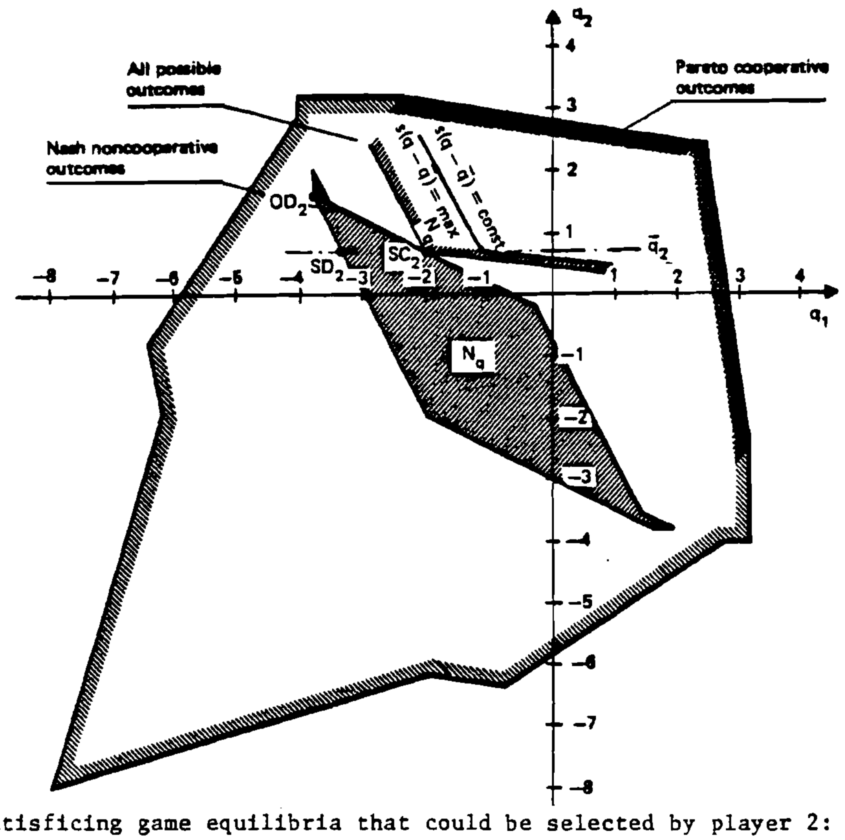

Fig. 4. Satisficing game equilibria that could be selected by player 2: SC_2 represents a constructive satisficing move; SD_2 represents a hidden destructive satisficing move; OD_2 represents an openly destructive move. $s(q-\bar{q})$ represents a maximized function that helps to select a constructive satisficing strategy.

Thus, the concepts of Stackelberg leadership and Stackelberg disequilibrium explain how open conflicts can occur--however, the explanation is not completely satisfactory since conflicts do not usually develop to this scale immediately. Historical evidence shows that if one country were to send its fishing fleet to another's waters, the other country would not necessarily reciprocate; in order to secure international support, the injured country would prefer to limit the fishing war to its own waters. We therefore need some additional concepts that could explain the processes of conflict escalation and de-escalation.

SATISFICING BEHAVIOR AND SELECTION OF GAME EQUILIBRIA

We have already seen that conflict escalation might be caused by some players having inflated aspirations, i.e., wishing to exceed the limits imposed by the natural (physical, biological, etc.) characteristics of the game. We should therefore consider a type of decision-making behavior related to the concept of aspiration levels--*satisficing behavior*. As originally introduced (Simon, 1959), this type of behavior is based on the idea that a decision-maker does not optimize due to uncertainty about various aspects of the problem, including the reactions of other decision-makers, and is thus satisfied if he reaches certain adaptively formed aspiration levels for specific objectives. This does not explain, however, what a decision-maker would do if certain outcomes were below his aspiration levels; we might safely assume that he would first try to reach his aspiration levels (which is equivalent to maximizing the outcomes if they are below these levels--see Kortanek and Pfouts, 1982) and would then either rest after achieving his targets, or change his aspirations. This type of behavior will be called *strict satisficing*; although of considerable interest,[5] it is still not sufficiently flexible to explain the process of conflict escalation.

A more flexible concept is that of *quasi-satisficing behavior*: players maximize their objectives, but with a greater intensity below their aspiration levels than above them. Mathematically, such a distinction seems to have no sense: payoff maximization behavior is not changed by the intensity of maximization, and the set of Nash equilibria is not changed by assuming quasi-satisficing behavior. However, quasi-satisficing behavior might influence the way a player selects a Nash equilibrium: having attained his aspiration level, he might devote his remaining freedom of action to some other purpose, such as constructively preventing conflict escalation by letting other players maximize their objectives, or destructively hurting other players by trying to negatively affect their objectives.

In the example from the previous section, the satisficing Nash equilibria for player 2, who has some aspiration level $\bar{q}_2$, are all of the Nash equilibria above and including the line $q_2=\bar{q}_2$ (see Fig. 4). Selection of the point SC_2 that satisfies $q_2=\bar{q}_2$ and is also good for the other player is a *constructive satisficing strategy*; selection of the point OD_2, which is the worst possible for the other player, is an *openly destructive strategy*;[6] selection of the point SD_2 that satisfies $q_2=\bar{q}_2$ but is the worst choice for the other player on this line is a *hidden destructive satisficing strategy*. The interpretation of the difference between constructive and hidden destructive satisficing strategies in the example considered is quite interesting. The parameters of the example are such that fish stocks are already heavily depleted and fishing in coastal waters hurts the host country more than it benefits the fishing country. A constructive satisficing strategy is then to decrease as much as possible your catch in the coastal waters of others (bearing in mind your economic aspirations), while imposing the strictest possible restrictions on outsiders fishing in your own waters. A hidden destructive strategy is to achieve the same economic aspiration level by fishing as much as possible in the coastal waters of others and imposing only such restrictions on foreigners fishing in your own waters as are necessary to attain your aspiration level. Each hidden destructive strategy can be 'rationalized' by invoking some seemingly plausible argument, for example, 'we believe in the freedom of fishing and restrict it only out of economic necessity'; nevertheless, it still remains destructive in the eyes of the other player.

A satisficing game equilibrium can be selected unilaterally when the aspiration levels of a particular player and the type of action to be taken (constructive, hidden destructive, etc.) are known; if the multiple objectives of the other side are to be taken into account, it is also necessary to have at least estimated aspiration levels for the other side. In fact, no matter whether you want to be constructive or destructive, you must have some idea of the aspirations of the other player--say, what economic and what ecological results would satisfy him; only when you assume (simplistically) that

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[5] See Part II of this paper.

[6] In this case (although not necessarily in general), the openly destructive strategy OD_2 coincides with the Stackelberg maximizing strategy.

the other player has only a single objective can you disregard his aspirations. A satisficing game equilibrium for a given mathematical model of the game can also be computed by maximizing an appropriate function over the set of Nash (or Pareto-Nash in the multiobjective case) game equilibria.[7] In the simple example considered here, the constructive satisficing option for player 2 with aspiration level $\bar{q}_2$ can be computed by solving the following prolem:

$$\underset{x\in N}{\text{maximize}} \ \frac{1}{\rho}\,(f_2(x)-\bar{q}_2)_+ - \rho(\bar{q}_2-f_2(x))_+ + f_1(x) \qquad (5)$$

where

$$N=\{x\in X:\ \min_{y\in X} \phi(x,y)=0\}\ ;$$

$$\phi(x,y)=\sum_{i=1}^{2}\,(f_i(x^{\hat{i}},x^i)-f_i(x^{\hat{i}},y^i)) \qquad (6)$$

and $\rho >> 1$ is a coefficient. If we denote $s(q-\bar{q})=\frac{1}{\rho}\ (q_2-\bar{q}_2)_+ - \rho(\bar{q}_2-q_2)_+ + q_1$, then the equivalent problem $\max_{q\in N_q} s(q-\bar{q})$ can be interpreted in outcome space as shown in Fig. 4. We see that it is necessary to maximize a nondifferentiable function over a non-convex set: although this is a difficult problem, it is not beyond the capabilities of modern optimization techniques (see Nurminski, 1982; Demyanov, 1983).

CONFLICT ESCALATION AND DE-ESCALATION

Figure 5 illustrates a process of conflict escalation, structured using the concept of selecting satisficing equilibria. We assume that both players have chosen satisficing constructive strategies SC_1, SC_2 at some $\bar{q}_1,\bar{q}_2$, but these aspiration levels are mutually incompatible and thus the overall result of these two decisions, 0_0, is not an equilibrium point. Suppose that player 1 decides, in the next round, to influence the aspirations of player 2 downwards by choosing hidden destructive SD_1; player 2 does not change his strategy, and the joint outcome is 0_1. However, since player 2 will probably recognize the destructive character of the move of player 1, he will not necessarily respond by revising his aspirations downwards; he might rather choose an openly destructive policy OD_2, which leads to the outcome 0_2 in the next round. If player 1 reciprocates, the next round results in an open fishing war, 0_3. By playing a game of this type structured using aspiration levels and the distinction between constructive and destructive behavior, participants can learn much about the dynamics of conflict escalation.

Similar techniques can be used to illustrate conflict de-escalation; however, implicit or explicit negotiations or mediation are needed for conflict de-escalation, even if this only involves unilateral decisions. We use the term "implicit negotiations" to describe a unilateral statement from one of the players that he wants to de-escalate conflict; he then modifies his actions in anticipation of similar behavior from the other side. In explicit negotiations, however, he would discuss such actions with the other side before actually implementing them. Mediation involves a third party who assists in the negotiations. These well-known situations can be illustrated by a gaming model used in a decision-support mode. Even if the actual aspiration levels of each player should be treated as confidential by the decision-support system (precise knowledge of the aspirations of the other side gives a player a strategic advantage), decision-supported gaming helps the players both to adjust their own aspirations and to learn about the aspirations of the others.

A simple process of this type is illustrated in Fig. 6. Suppose both players have chosen constructive satisficing moves $SC_{1,1}$ and $SC_{2,1}$, but their aspiration levels are far from being compatible and the result of their decisions is 0_0. Suppose, through implicit negotiations or under the influence of the mediator, player 1 decides to revise his aspirations downward and chooses a constructive satisficing strategy $SC_{1,2}$; this leads to 0_2 in the next round, which is slightly better for player 1 and much better for player 2. The crucial point is whether player 2 will reciprocate; if he does, choosing $SC_{2,2}$ which leads to outcome 0_2, then player 1 might be motivated to go further, selecting $SC_{1,3}$ and outcome 0_3; player 2 may then select $SC_{2,3}$ and outcome 0_4. At this point, the differences between aspiration levels and actual outcomes are so low that the players can agree to accept the outcome 0_4 as a negotiated status quo.

An active mediator can be helpful even when players will not consider multilateral actions and proceed unilaterally; in fact, a mediator might even be necessary to stimulate conflict de-escalation through unilateral action. If the mediator enjoys the

[7] See Part II of this paper.

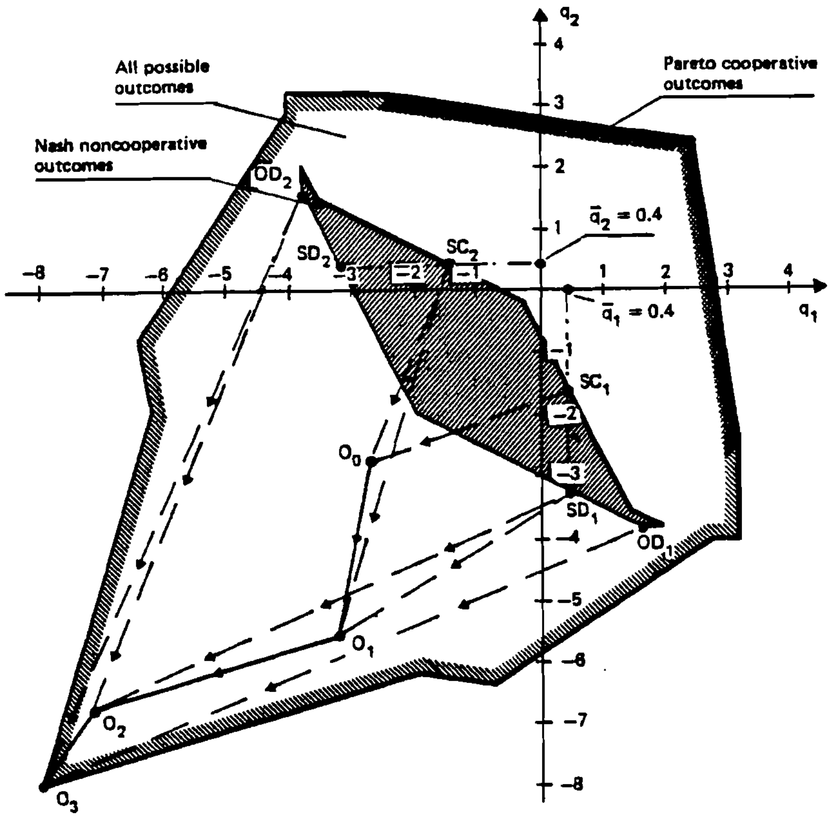

Fig. 5. A case of conflict escalation. SC_1, SC_2 represent satisficing constructive moves for players 1 and 2; SD_1, SD_2 represent satisficing (hidden) destructive moves for players 1 and 2; OD_1, OD_2 represent openly destructive moves for players 1 and 2. The conflict escalation process is represented by $(SC_1, SC_2) \Rightarrow O_0$; $(SD_1, SC_2) \Rightarrow O_1$; $(SD_1, OD_2) \Rightarrow O_2$; $(OD_1, OD_2) \Rightarrow O_3$.

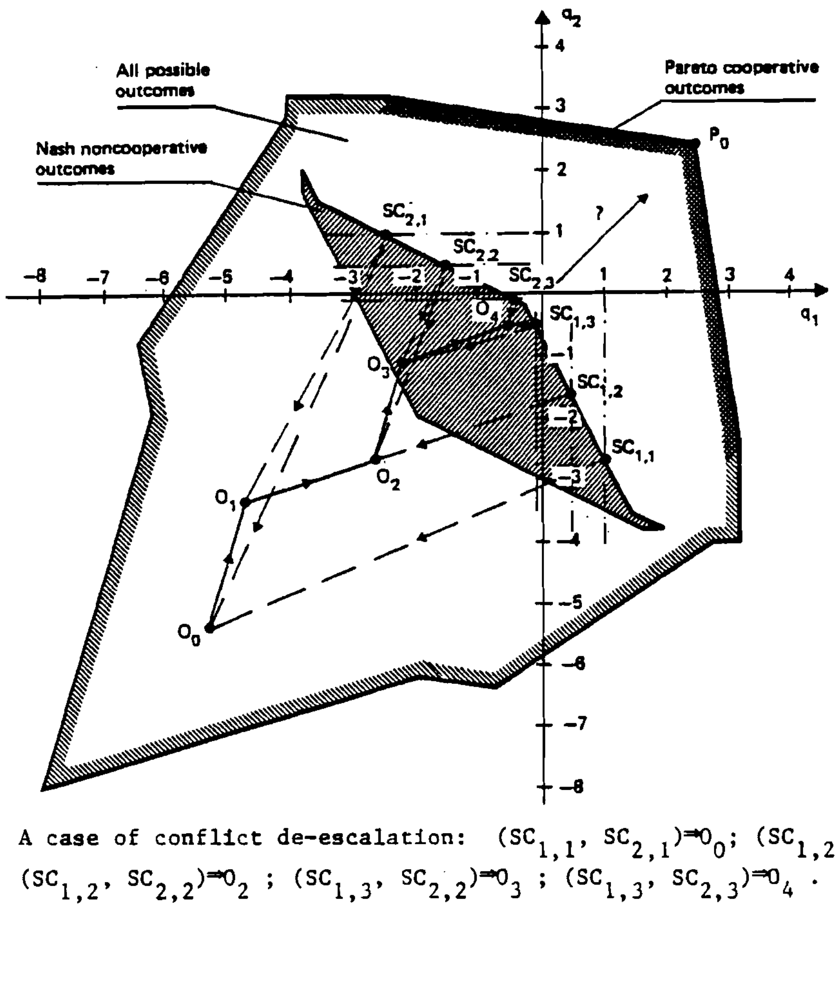

Fig. 6. A case of conflict de-escalation: $(SC_{1,1}, SC_{2,1}) \Rightarrow O_0$; $(SC_{1,2}, SC_{2,1}) \Rightarrow O_1$; $(SC_{1,2}, SC_{2,2}) \Rightarrow O_2$; $(SC_{1,3}, SC_{2,2}) \Rightarrow O_3$; $(SC_{1,3}, SC_{2,3}) \Rightarrow O_4$.

confidence of both sides and knows their aspiration levels, he can mediate in the *choice of game equilibria* (Fig. 7). To do this, he could use the information contained in two points: the current outcome of the game, point 0_0, with outcome levels $\tilde{q}_1, \tilde{q}_2$, and the current aspiration levels $\bar{q}_1, \bar{q}_2$. A game equilibrium selected via mediation can be defined, for example, as a solution of the problem:

$$\alpha = \max_{x \in N} \min_{i=1,2} (f_i(x) - \tilde{q}_i)/(\bar{q}_i - \tilde{q}_i) \qquad (7)$$

where N is defined as in (6). The value of α (measured as the distance between the current aspiration levels and the current outcome) gives some idea of how much both sides should decrease their aspiration levels in order for the players to unilaterally select mutually consistent game equilibria.

Clearly, the players might do much better by agreeing on multilateral action, leading to outcomes in the neighborhood of the point P_0. However, explicit negotiations or mediation are required to obtain agreement on multilateral action (such as the historic agreement on sovereignty over coastal waters).

MEDIATION TO OBTAIN AGREEMENT ON MULTILATERAL ACTION

Attempts to reach agreement on multilateral action always start with an assessment of the noncooperative status quo. The status quo is not necessarily a result of conflict de-escalation, such as the point 0_4 in Fig. 6; it could just as well be the result of conflicting strategies, such as the point 0_0. However, a status quo can always be established in a gaming model, if only by repeated gaming simulations.

Actual negotiations often proceed without a mediator, and are structured by the proposals or positions of the parties involved; these positions are successively modified in the course of negotiations. While the dynamics of such negotiations are, in general, a very interesting topic (see Raiffa, 1982), we shall limit our attention here to negotiations involving a mediator. By agreeing to the use of a gaming model that represents some substantive (physical, biological, etc.) aspects of the system, the parties involved also implicitly agree to the model as mediator. As a starting point for possible further investigations, we shall also assume that the parties involved also agree on some rules of fairness for dividing the benefits gained from multilateral action, and on the use and assessment of the proposals generated by the decision and mediation support system according to these accepted rules of fairness (see Fisher and Ury, 1981).

There are many principles by which common gains or costs measured in comparable units can be divided fairly among the participants: there is the classical principle 'one divides, the other chooses'; the Steinhaus generalization of this principle to many participants; and many other procedures of various types (see Young et al., 1982). There are also many ways of defining cooperative solutions to single-payoff games (the concepts of core, nucleolus, Shapley value, etc.--see Shapley, 1965; Aubin, 1979); however, these concepts are not easily extended to multiobjective games. A type of cooperative solution that can be relatively easy extended to multiobjective games was proposed first by Raiffa and then by Kalai and Smorodinsky (1975); we present a modification of this idea as a possible principle for fair division of joint gains made in a multiobjective game.

Assume that a noncooperative status quo has been reached in the game (for example, through simulation gaming, or noncooperative gaming with decision support). Let $\tilde{q}^i_j$ denote the status quo value of the j-th objective or outcome for the i-th player, and assume that all outcomes should be maximized. Then the decision support system can compute the maximum possible increase in the value of each objective for each player, assuming cooperation between players:

$$\Delta q^i_j = \max_{x \in \tilde{X}} f^i_j(x) \ ; \ \tilde{X} = \{x \in X : f^{\hat{i}}_{\hat{j}}(x) \geq \tilde{q}^{\hat{i}}_{\hat{j}} \ , \ \text{for all } \hat{i},\hat{j} \neq i,j\} \qquad (8)$$

These maximum cooperative increases Δq^i_j are taken as units in the rule used to allocate joint gains. According to this rule, the cooperative gains $q^i_j(x) - \tilde{q}^i_j$ resulting from some multilateral decision x are allocated fairly if

$$\lambda^i_j (q^i_j(x) - \tilde{q}^i_j)/\Delta q^i_j = \alpha \leq 1 \qquad \text{for all } i,j \qquad (9)$$

where

$$0 \leq \lambda^i_j \leq 1 \quad ; \quad \sum_{j=1}^{P_i} \lambda^i_j = 1 \qquad (10)$$

and P_i denotes the number of objectives considered by each player. The λ^i_j are corrective scaling coefficients specified by each player after reviewing proposed cooperative outcomes, and indicate how he would prefer to allocate gains among his own objectives. (The decision support system can start with the assumption that $\lambda_j^i = 1/P_i$.) However, since the coefficients sum to 1 for each player, and α is a joint coefficient for all players, the allocation of gains between players is determined (using the rule of fair division) by the proportion of actual gains to the maximum cooperative gains.

Clearly, such a rule must have some ad hoc character, although it must also possess certain normative properties.[8] It should be stressed that there is no ultimate principle of fairness in any complicated game (say, a sporting game) and that ideas of fairness develop historically: a set of rules is fair if it does not fundamentally favor any of the players and if it is accepted by all players.

Following the rules of fairness (8-10), the decision and mediation support system could compute a decision x that would maximize the coefficient α in (9) for given λ_j^i. However, since the players should have time to assess the proposed cooperative outcomes and to adjust the allocation of gains among their own objectives by modifying λ_j^i, the mediation support system should not propose maximum gains (maximum α) in the first iteration. If the largest attainable value of α is, say, α_m, the first iteration should produce a cooperative decision that would satisfy (9) with $\alpha = \beta\alpha_m$, where $\beta \in (0;1)$ is a chosen coefficient. This proposal can then be presented, together with its outcomes, for assessment by the players. There are two main questions here: whether the proposed decision is acceptable to all players, and whether they would like to modify previous λ_j^i. If all players agree that the proposed decision is acceptable, then the process is repeated using this decision as a starting point; if not, the previous acceptable decision (the starting point) is adopted (the status quo is by definition acceptable). Under additional procedural restrictions, this process can be shown to converge to a Pareto cooperative decision and outcome (see Part II of this paper). In a single payoff game, such as that illustrated in Fig. 8, this process is very simple, since the players cannot influence the direction of increasing gains in outcome space; in a multiobjective game, however, they can influence this direction, but only in the subspace containing their own outcomes of interest.

[8] See Part II of this paper.

Finally, we should stress the obvious fact that the decision and mediation support system described here addresses only a small subset of the problems that might be encountered in mediation. For example, to obtain specific agreements that stabilize cooperative Pareto solutions would require an independent analysis. Although a Pareto cooperative solution might be stabilized over a number of sessions through the simple threat of a return to a noncooperative equilibrium worse for all players, the way in which a repetitive prisoner's dilemma problem is handled depends on the cultural background of the parties involved: some players might be tempted to defect from a Pareto solution for one-sided gains. Thus, most specific agreements require special provisions to enforce them--such as specifying penalties for "cheating" that actually change the original game into a new one in which the agreed solution becomes a unique Nash equilibrium.

A FRAMEWORK FOR A DECISION AND MEDIATION SUPPORT SYSTEM FOR INTERACTIVE GAMING

All of the above analysis shows that it is possible to construct a decision and mediation support system for interactive gaming experiments. The purpose of such systems is, first, educational: to provide players with a vehicle for learning about conflict and cooperation in structured way, using games based on their own field of interest. However, these systems could also be used for research purposes (e.g., to analyze specific examples of conflict and cooperation); in the future, they may even be used in real negotiations.

Since many gaming experiments begin with interactive model building (see, e.g., Holling, 1978), which also involves simulation gaming, we could say that the initial mode of such a decision and mediation support system is *simulation gaming* (this includes interactive model building and joint validation with model users). Even in this phase, the supporting team of analysts might include a facilitator or chief analyst who will help in mediation in later phases. It should be stressed that the model and decision support system always play a service role in such experiments; human interaction is the most important element. Therefore, whenever we speak about mediation support here, it should not necessarily be assumed that this support is extended by the computer system directly to players; the facilitator may just use the suggestions made by the computer system in discussions with the players.

The second mode of the system is *game analysis*. The behavior of players when they approach a gaming experiment for the first time is quite different from their behavior when they have already played the

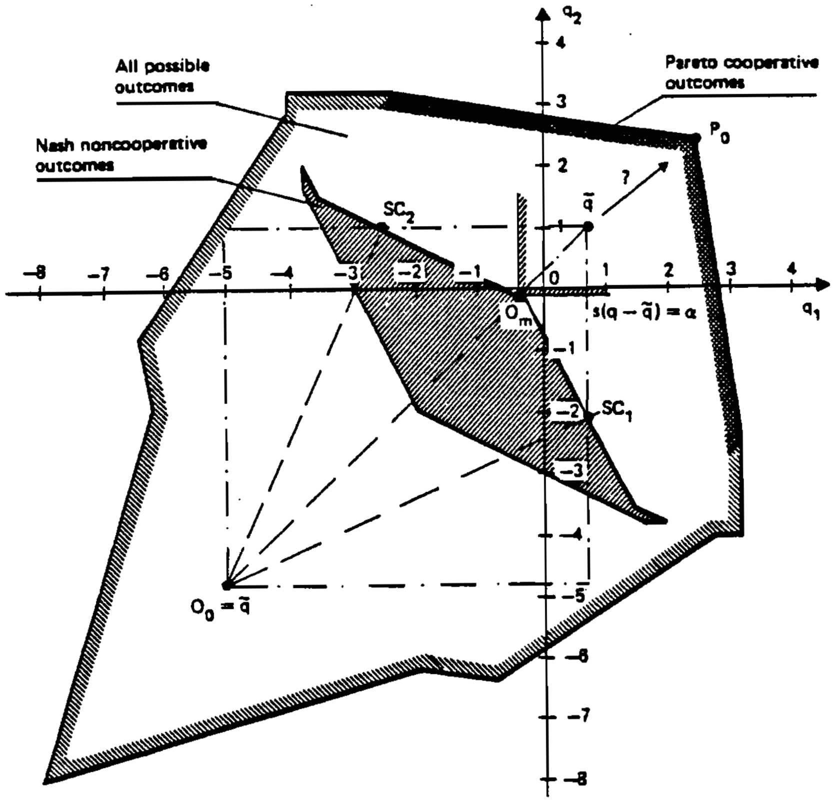

Fig. 7. Mediated selection of game equilibria: SC_1 represents a unilateral constructive move for player 1; SC_2 represents a unilateral constructive move for player 2; O_0 represents the joint disequilibrium outcome; $s(q-\tilde{q}) = \min_{i=1,2} (q_i-\tilde{q}_i)/(\bar{q}_i-\tilde{q}_i)$; O_m represents the outcome corresponding to the mediated game equilibrium.

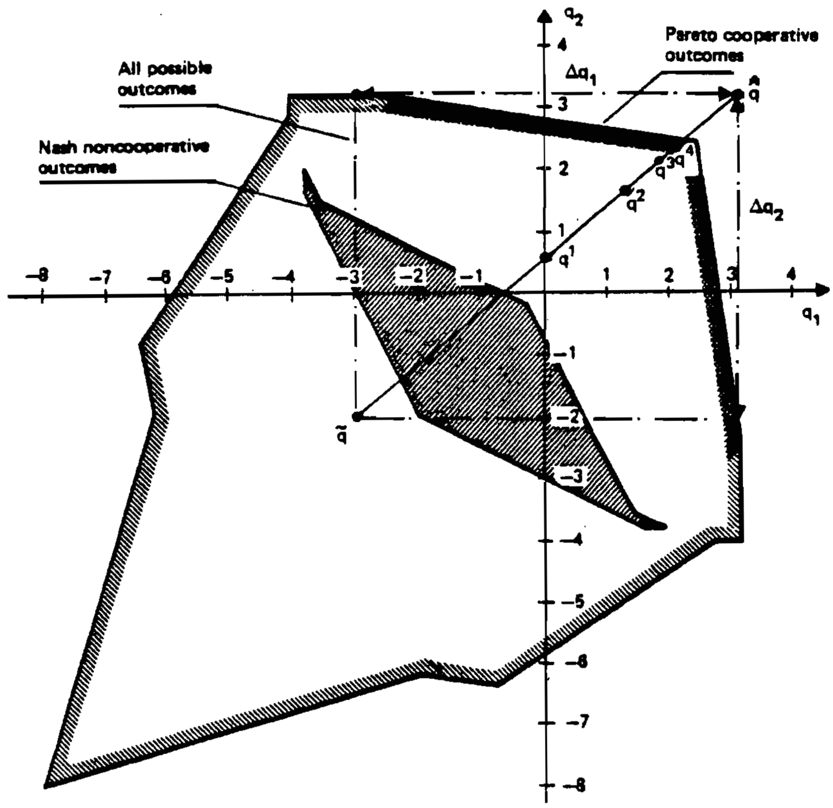

Fig. 8. Multilateral cooperative improvements: $\tilde{q}$ represents the status quo outcome; $\Delta q_1, \Delta q_2$ represent the maximum cooperative increases; q^1, q^2, q^3, q^4 .. represent the outcomes of successive decisions proposed by the mediator.

game a few times and analyzed it. In order to stimulate game analysis, the decision support system can provide the player with various pieces of information about the game, such as the game images that illustrate this paper. After a discussion of the basic properties of the game, the simulation gaming experiment can be repeated, and the behavior of the player monitored.

The third mode of the system is *unilateral decision-supported gaming*. If the system is equipped with programs for computing unilateral satisficing equilibria, a player can request several computer-assisted analyses before making his move. After specifying his own aspiration levels and estimating those of the others, he can request the support system to compute his own satisficing (constructive or destructive) options, to predict the moves of the other players, the estimated joint outcomes, etc., and only then decide upon his move.

The fourth mode of the system is *unilateral decision and mediation supported gaming*. This mode assumes an active mediator, who could be the facilitator and organizer of the game although at this stage he cannot propose joint actions but only suggest modifications of unilateral actions. He can do this because the aspiration levels of all players, although not known to each other, are known to the decision support system and the mediator. The mediator can thus use the system to compute mediated game equilibria and suggest reasonable adjustments of their aspirations to the players.

The fifth and final mode of the system is *mediation support for multilateral agreements*. In this mode the mediator suggests cooperative actions to the players, these suggestions are assessed by the players, and their responses are then used by the mediator and the support system to generate new proposals.

Clearly, not all of these modes will be necessary in every application: for example, players might decide to go directly to the fifth mode after completing the first and second phases.

CONCLUSIONS

We conclude that it is in principle possible to build decision and mediation support systems for use in interactive gaming; we believe that such systems could contribute considerably to our understanding of conflict processes. Such support systems are currently being developed at the International Institute for Applied Systems Analysis to analyze (among other things) fishery conflicts, North-South economic relations and national policies for long-term energy planning.

There is also an important methodological conclusion: explicit analysis of the changes that take place in aspiration levels as conflicts develop might take us a long way toward understanding conflict processes. The examples given in this paper indicate that inflated aspirations lead to conflict escalation, while a downward revision of aspiration levels leads to conflict de-escalation; this property seems to be quite general, but requires further study.

The second part of this paper will address in more detail the mathematical aspects of the concepts discussed here.

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