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Cross-Impact Gaming Applied to Global Resources

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CROSS-IMPACT GAMING APPLIED TO GLOBAL RESOURCES

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Preface

IIASA, according to its charter, has an inherent interest in a systems approach to the global-resources problem. In fact, IIASA has sponsored a series of conferences designed to survey and monitor global modeling efforts conducted elsewhere. The present paper describes a methodological approach to the kind of global planning that might help avert the detrimental consequences of an unchecked continuation of current population and industrialization trends.

Thanks are due to Günther Fischer for formulating the computer program for the gaming model presented in this paper.

Abstract

A number of efforts to deal with the problem of shrinking global resources have succeeded in alerting the public to the consequences of a continuing laissez-faire attitude in the face of currently observable population and industrialization trends, but little has been done to provide positive as well as realistic plans for countering the threats of such disasters.

A systematic move in the direction of constructive global planning will have to be based on a new kind of model which includes reactions to uncertain contingencies as they arise. The present paper is intended to provide a methodological approach to the design of planning models appropriate for this purpose.

The illustration presented here, in contrast to traditional approaches, has the form of an interactive simulation model. In addition to trends, such as population, pollution, or per-capita food supply, it also includes events. The latter are of two kinds: stochastic occurrences, such as technological breakthroughs, which represent uncertain contingencies; and deliberate interventive reactions to these contingencies, such as legislative acts, treaties, or R+D efforts.

A full-fledged attempt to apply such precepts to global planning would require a very substantial effort. The present paper represents a first methodological step toward the implementation of such an endeavor.

CROSS-IMPACT GAMING APPLIED TO GLOBAL RESOURCES

In an earlier publication[1] I pointed out that the system-dynamics approach to the global-resources problem[2] has certain deficiencies in that it represents a deterministic rather than stochastic model and that it considers the interrelations among trends only instead of among events as well as trends. The second of these seems to be the more serious shortcoming, and it is, in this respect, in the good company of standard econometric models, which similarly can only be made to respond to sudden exogenous perturbations through the device of a "systems break"[3], i.e., an abrupt switch to a different set of input parameters.

The publication of the Limits-to-Growth study has had the immensely beneficial effect of alerting people throughout the world to the catastrophic implications within the twenty-first century of doing nothing to prevent a continuation of present trends in resource depletion and rising population levels. This warning having been effectively conveyed, however, it is imperative that a constructive approach be initiated in the form of a plan of action that will forestall the dire global consequences of inaction.

As conditions get worse--insufficient food per capita, inadequate energy supply, depleted mineral resources, an insufferably polluted environment--it is inconceivable that governments throughout the world would passively sit by and be content watching the demise of civilization. In fact, interventive events would inevitably take place, in the form of regulative, legislative, and diplomatic actions, as well as of a reinforced endeavor to bring about the technological advances required to halt the observed trends toward disaster.

To cope with the development of global plans for moving in this direction, it is necessary to design a new type of model, capable of systematically handling the occurrence of interventive events. The construction, in detail, of such a model, because of the obviously enormous complexity of the subject matter, requires a very considerable effort by a team at least comparable in size and in cross-disciplinary diversity to that of the Meadows team. In this article, I wish merely to indicate a methodological approach to this task, using cross-impact gaming. I hasten to add that the concepts offered here are in need of, and deserve, a good deal of further refinement[4] and that the numerical examples are included strictly for illustrative purposes and carry no claim to verisimilitude except in order-of-magnitude terms.

The construction of a cross-impact model requires the following selections:

(1) The time horizon; in the present case: 2027.

(2) The temporal "resolution", i.e., the fineness of the temporal grid; for this we have chosen 5 years. In other words, the entire 50-year period under consideration, from the present to 2027, is divided into 10 "scenes" of 5 years each.

(3) The decision-makers to be explicitly represented; for illustrative purposes, we have chosen (a) the U.N., (b) the U.S., and (c) OPEC. They are the "players" in the cross-impact game to be constructed.

(4) The potential future events that have a nonnegligible chance of occurring and that would, if they occurred, have a profound effect on the situation under consideration. In the present case, 9 such events have been included:

E1: Breeder reactor (the placing into operation of the first breeder reactor with a capacity of at least 500,000 kw)

E2: Solar power plant (the placing into operation of the first solar power plant with a capacity of at least 500,000 kw)

E3: Fusion power plant (the placing into operation of the first fusion power plant with a capacity of at least 500,000 kw)

E4: Storage battery (a technological breakthrough making it economically feasible to store large quantities of electricity)

*E5: Mineral extraction (a technological breakthrough in mineral extraction--including, for example, ocean mining and the use of satellites for detection of ore deposits--making it possible to extract minerals at less than half of the previous cost)

*E6: Depollution (a technological breakthrough in depollution, making it possible to achieve depollution at less than half the previous cost)

*E7: Nonagricultural food (a technological breakthrough in nonagricultural food production, such as aquaculture or manufacture of artificial protein, making it economically feasible to increase the previous world food production by at least 20%)

E8: Weather control (a technological breakthrough making it economically feasible to bring about substantial regional weather changes)

E9: Transmutation (a breakthrough in physics making it economically feasible to manufacture many chemical elements from subatomic building blocks and thus to convert abundantly available low-grade substances into high-grade raw materials)

It is important to note that none of these events directly represent potential player decisions. Most of them, if not all, however, can be affected by such decisions. Some events, annotated with asterisks, are potentially recurrent; the remainder may occur only once.

(5) The trends that ought to be monitored because any unexpected deviations of their values from their anticipated courses would profoundly affect the situation under consideration. The following 11 such trends were selected:

T1: World population (in billions)

T2: Food per capita (using an index value of 100 for 1977)

T3: Pollution (an overall index of pollution, on a scale from 0 [= no pollution] to 100 [= all life extinct], with the 1977 level set arbitrarily at 25)

T4: Raw materials (the known reserves of nonrenewable raw materials, other than fuel, that are economically exploitable by existing extraction methods, using an index value of 100 for 1977)

T5: Industrial output per capita (using an index value of 100 for 1977)

T6: Birth control acceptance (the percentage of the world's population who in principle have accepted the idea of birth control)

T7: Acreage productivity (a world average, using an index value of 100 for 1977)

T8: Energy production (the total production of all forms of energy, using an index value of 100 for 1977)

T9: Investment fraction (the amount of investment in capital goods, expressed as the percentage of the sum of such investment and personal consumption expenditures)

T10: Harvest conditions (the average harvest conditions, as determined by weather, pests, diseases, and natural catastrophes, measured on a scale from 0 to 100, with the 1977 level set arbitrarily at 50)

T11: Quality of life (a world average, measured on a scale from 0 to 100, with the 1977 level set arbitrarily at 50)

We note that the first five of these are identical with the five principal trends whose interactions were investigated in the Limits-to-Growth study.

(6) The actions that the players may take. Among the many that might have been chosen, the following were selected to illustrate the potentials of a gaming application. The parenthetical letters refer to the players (a=U.N., b=U.S., c=OPEC):

A1: Ban on fission reactors (a,b)

A2: Depollution treaty (a)

A3: Establishment of a world food bank (a)

A4: Global agritechnology transfer (a,b)

A5: Oil supply disruption (c)

A6: Law discouraging energy waste (b)

A7: Global birth control propaganda (a,b)

A8-A16: R+D to promote E1-E9 respectively (b)

A17: R+D to promote T5 (b)

A18: R+D to promote T10 (a,b)

(7) A budget for each player and each scene, as well as price tags for the actions (as a function of the intensity of their enactment, where appropriate). The details in this regard will not be included in this report.

Having thus chosen the elements to be represented in the model, the next step is to provide some numerical estimates for the input data. Except for the present, 1977, situation (the initial status of Scene 1), all of the inputs refer to the future; hence, by their nature, they can at best be based on extrapolations from the past but in all cases require some expert judgment. To obtain such judgmental data, a method such as Delphi might recommend itself. In particular, the following estimates are required (and the specific numbers chosen, as stated before, since they are illustrative only, are intended to be accurate only in their order of magnitude):

(8) The probabilities of occurrence, within each scene, of the events. In the case of nonrecurrent events, each number indicates the probability conditional upon the event not already having occurred in an earlier scene:

Scene	1	2	3	4	5	6	7	8	9	10
E1	.04	.12	.20	.24	.22	.14	.09	.07	.06	.05
E2	.02	.10	.35	.50	.60	.65	.70	.75	.80	.85
E3	.00	.00	.02	.06	.15	.30	.40	.44	.43	.40
E4	.10	.25	.35	.40	.40	.35	.30	.25	.20	.15
E5	.10	.19	.27	.34	.40	.45	.49	.52	.54	.55
E6	.05	.07	.10	.15	.20	.25	.29	.32	.34	.35
E7	.01	.02	.04	.06	.09	.12	.16	.20	.25	.30
E8	.01	.02	.04	.06	.09	.12	.16	.20	.25	.30
E9	.00	.00	.01	.01	.02	.02	.03	.03	.04	.04

(9) The anticipated trend values at the beginning of each scene, from 1 to 11, where the value at the beginning of Scene 11 of course represents the terminal value for Scene 10:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.3	4.7	5.0	5.3	5.6	5.9	6.1	6.3	6.5	6.7
T2	100	96	93	92	92	93	94	95	97	100	102
T3	25	30	34	37	39	40	40	36	31	26	20
T4	100	95	90	85	81	78	81	85	90	96	103
T5	100	101	103	106	110	115	121	128	136	145	155
T6	20	24	28	32	36	40	44	48	52	56	60
T7	100	101	103	106	110	115	121	128	136	145	155
T8	100	110	120	132	145	160	178	197	217	240	264
T9	20	21	22	23	24	25	26	27	28	29	30
T10	50	51	52	53	54	55	56	57	58	59	60
T11	50	48	45	42	40	41	42	44	48	53	60

(10) The volatility, v, of the trends, i.e., the precision (or lack of it) to be attached to scene-by-scene trend forecasts. For example, if the value of T1 at the beginning of Scene 5 should, indeed, turn out to be 5.3 as indicated above, the forecast of 5.6 for the end of that scene (= the beginning of Scene 6) should be interpreted as being a value drawn from a normal distribution about 5.6 whose quartiles are at 5.6 ± v. For simplicity, the values of v have been assumed to be constant for all scenes, as follows:

T	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
v	.05	2	1.5	2.5	4	3	3	5	.5	5	2.5

The randomization introduced in this manner simulates exogenous sources of uncertainty with which a planner would be faced in the real world.

(11) The cross impacts among the developments (i.e., the selected events and trends). These are tabulated in matrix form, where each number represents the effect of the development listed on the left upon that listed above:

	E1	E2	E3	E4	E5	E6	E7	E8	E9	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
E1		-.8-	-1-						.6-			-2+					2+			-1-
E2	-2-		-1-	1-								-4+					3+			
E3	-2.4-	-1.2-							.6-			-4+					2+			
E4		2-										-2+				1+				.4+
E5									-1.2-				3+							
E6	-.8-	-.6-	-.6-									-5+								.5-
E7								-.6-			3+					-.5-		.5-		
E8												-1=							1+	.6=
E9	.8=		.8=		-1-								5+					1-		
T1		.3	.2				.3			.95	$-\frac{2.5}{T}$	.25		$-\frac{1.5}{T}$	|1|	.1		-.05		
T2							-.2			.8 (<100)	.2			.1						.6
T3	.2	.4	.2			.8				-.5 (>30)		.1							-.1	-.3
T4					-.2			-.2					.3	.2 (<100)						
T5												.3	-.8		.2	.3		-.2		.2
T6										-.2					.6					
T7							-.2				$\frac{150}{T}$					.6				
T8	-.4	-.4	-.4										.6	1		.3	.2	.2		
T9	.6	.6	.4	.6	.6	.6	.4	.4	.4					1.5		.3	.35	.2		-.3
T10							-.2				2									
T11																		.2		

In the case of an event, the effect derives from its occurrence or nonoccurrence; in the case of a trend, the effect is in general proportional to the size of its deviation, measured in volatility units, from the anticipated value. The effect of a cross impact upon an event is to raise or lower its probability of occurrence in subsequent scenes; the effect of a cross impact upon a trend is to raise or lower its subsequent values, again measured in volatility units. (A '+' or '-' or '=' after an entry signifies that the impact in later scenes increases, decreases, or remains the same; otherwise the impact occurs only once, namely in the next scene. A parenthetic inequality '< 100' or '> 30' signifies that the impact occurs only if the value of the impacting trend is less than 100 or more than 30, respectively. The symbol '$|1|$' signifies that the impact occurs only if the impacting trend deviates positively from its anticipated value.)

(12) The impacts of any actions. Here, as in (7), details are omitted in this presentation.

The model should now be ready to run. To begin with, to check the proper performance of the model, it is best to conduct a number of "basic runs", in which no interventive actions are taken. A single such run proceeds as follows:

In Scene 1, "decide" (by a standard Monte Carlo drawing of random numbers) which of the events occur; adjust the event probabilities and trend values for Scene 2 according to the cross-impact matrix; then proceed to Scene 2, having adjusted the trend values further by adding random volatility deviates. Again decide which events are now occurring, and also observe the deviations of trend values from their anticipated values as of the beginning of Scene 2; adjust the event probabilities and trend values for Scene 3 according to the cross impacts caused by event occurrences (or nonoccurrences) and trend value deviations. Repeat the procedure for Scenes 3,4,...,10. The result will be a "scenario" of event occurrences, by scenes, and of trend value adjustments.

Two basic runs will yield different scenarios because of the random effects that are present. A large number of runs should produce average trend values close to the input values and frequencies of event occurrences in each scene that closely reflect the input probabilities. The result of 10 basic runs is shown below:

Exhibit 1: 10 Basic Runs

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1		1	5	2						
E2		1	3	1	4				1	
E3					1			2	1	1
E4		4	1	3	1			1		
E5		4	3	5	3	4	5	5	4	3
E6				4	4	1		1	1	1
E7				1	1	2				1
E8		1			3		1	2	1	2
E9						1	1		1	1

Average trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.3	4.5	4.6	4.8	4.9	5.1	5.4	5.7	6.0	6.3
T2	100	99	97	96	93	97	107	113	120	123	125
T3	25	32	33	34	29	25	23	22	19	14	12
T4	100	90	83	82	86	97	106	116	122	135	145
T5	102	101	106	110	121	138	161	185	194	199	203
T6	20	26	32	36	39	45	49	55	63	71	71
T7	101	102	108	108	114	125	142	161	174	185	190
T8	102	113	121	137	158	192	227	262	299	326	352
T9	20	21	22	23	24	26	27	28	29	30	31
T10	53	54	51	50	52	59	63	62	64	65	65
T11	51	48	46	45	47	49	51	57	62	65	67

Next, some sensitivity runs should be carried out. For instance, one might ask: How different would the results be if Event E9 were to occur in Scene 1? or if Trend T2 were substantially lower than anticipated in both Scenes 1 and 2? The following tabulations permit a comparison of these cases with the basic case (where care has been taken to start each at the same random number entry, which guarantees that at analogous stochastic decision points we will be equally "lucky" or "unlucky" in all cases):

<u>Exhibit 2:</u> **1 Basic Run**

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1				1						
E2					1					
E3									1	
E4				1						
E5		1					1			
E6					1					
E7										1
E8								1		
E9							1			

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.2	4.4	4.5	4.4	4.5	4.7	5.0	5.5	5.8	6.2
T2	99	88	81	78	79	96	113	114	118	120	127
T3	26	33	32	38	37	28	23	25	20	14	12
T4	98	92	100	90	80	85	109	117	130	142	148
T5	99	86	96	126	133	111	154	184	193	198	204
T6	23	31	32	28	32	40	42	45	60	73	72
T7	95	90	95	100	106	122	129	145	164	187	188
T8	105	113	119	130	150	173	212	234	283	304	345
T9	19	20	24	24	22	24	27	29	29	31	31
T10	49	52	45	45	56	61	64	57	65	71	65
T11	50	49	37	32	34	39	49	59	57	68	66

Among the noteworthy features of this scenario are these: A very low level of T10 (harvest conditions) in Scenes 3 and 4 causes T2 (food p-c) to be very low in Scenes 4 and 5, in turn causing T1 (population) to be lower than expected thereafter; the occurrence of E1 (breeder reactor) and E2 (solar energy) in Scenes 4 and 5 causes T8 (energy production) to rise substantially above expected levels; the (unusual) occurrence of E9 (transmutation) in Scene 7 causes T4 (raw materials) to rise sharply toward the end.

Exhibit 3: E9 in Scene 1

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1			1							
E2					1					
E3									1	
E4				1						
E5		1					1			
E6										
E7										1
E8								1		
E9	1									

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.2	4.4	4.5	4.5	4.6	4.8	5.1	5.5	5.8	6.2
T2	99	88	81	79	83	102	116	116	120	120	127
T3	26	33	32	35	37	35	29	31	25	17	13
T4	98	105	121	115	112	121	143	142	154	159	138
T5	99	86	102	136	148	125	161	188	194	198	204
T6	23	31	32	29	33	44	47	48	63	74	72
T7	95	90	95	103	113	132	139	153	169	189	189
T8	105	113	120	140	157	181	219	241	289	308	349
T9	19	21	24	24	22	24	27	29	29	30	31
T10	49	52	45	45	57	61	62	55	64	70	65
T11	50	49	36	30	36	44	52	59	57	68	66

Compared to the basic run (Exhibit 2), in which E9 occurred only in Scene 7, T4 (raw materials) increases sharply in Scene 2 and thereafter (as expected), but the differential effect on T5 (industrial output), which is quite noticeable at first, declines toward the end since T4 then is above 100 in both cases. We note, too, that T7 (acreage productivity) and hence T2 (food p-c) show slight improvements in the middle range.

Turning now to the question of the sensitivity to T2 (food p-c), the results shown in the following exhibit were obtained:

Exhibit 4: T2 lower in Scenes 1 and 2

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1				1						
E2					1					
E3									1	
E4				1						
E5		1					1			
E6										
E7										1
E8								1		
E9							1			

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.1	4.1	4.3	4.4	4.6	4.7	5.0	5.5	5.8	6.2
T2	93	80	82	84	84	97	112	113	117	119	127
T3	26	33	31	36	36	34	28	30	25	17	13
T4	98	92	101	90	76	81	106	118	131	142	149
T5	99	85	98	133	139	113	151	183	192	197	203
T6	23	31	32	28	33	42	44	45	60	73	72
T7	95	90	94	99	105	123	129	145	164	186	188
T8	105-	113	119	130	149	173	211	233	283	303	345
T9	19	20	23	23	22	24	27	29	29	30	31
T10	49	52	45	45	57	61	62	55	64	70	65
T11	50	45	31	34	40	44	48	58	55	67	66

Compared, again, to the basic run (Exhibit 2), the effect of a lower T2 (food p-c) in Scenes 1 and 2 is to lower T1 (population) substantially thereafter at first (i.e., in Scenes 2 - 4); but the smaller population, in turn, causes T2, and consequently T1 itself, to rise again later, so that the final population figures toward the end are comparable to those of the basic case. These fluctuations also are reflected in the values of T11 (quality of life).

Similar in nature to a sensitivity test, such as exemplified by Exhibits 3 and 4, is the case of players' interventions. To illustrate a simple one-player intervention, we may examine the effect of an OPEC oil embargo in Scene 1. Again, to make direct comparisons with the basic case (Exhibit 2) possible, the same random-number entry point was chosen:

Exhibit 5: Action 5 by Player C in Scene 1

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1				1						
E2					1					
E3										
E4				1						
E5		1					1			
E6					1					
E7										1
E8								1		
E9							1			

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.2	4.4	4.5	4.4	4.4	4.6	4.9	5.4	5.7	6.1
T2	99	88	81	76	76	94	113	114	119	120	128
T3	26	33	32	37	36	28	22	25	20	16	13
T4	98	92	97	92	82	86	109	116	129	142	147
T5	99	86	90	121	132	112	156	185	193	199	203
T6	23	31	32	28	31	40	42	45	61	73	72
T7	95	90	93	98	104	121	127	144	164	186	187
T8	105	104	118	129	150	174	212	233	283	296	331
T9	19	20	23	24	22	24	27	29	29	31	31
T10	49	52	45	45	56	61	64	57	65	71	65
T11	50	49	37	32	32	36	48	59	57	68	66

The taking of Action 5 in Scene 1, except for its obvious immediate influence on T8 (energy) in Scene 2, has little lasting effect of any size. Yet, it is interesting to observe some of the minor repercussions, because they are typical of the kind of tertiary ricochet effects to which technology-assessment investigations have drawn some attention. Thus, the decline of T8 in Scene 2 causes T4 (raw materials) and T5 (industrial output p-c) to be low in Scene 3. But while the deterioration of T5 continues (reinforced by the decline of T4), that same trend causes T4 to recover in Scene 4. However, T4's recovery, in turn, sets off a recovery of T5, and so on, resulting in some slight oscillations of T4 and T5. T8's decline also causes a reduction in T7 (acreage productivity), which is passed on via T2 (food p-c) to T1 (population). The reduced population pressure causes efforts toward E3 (fusion energy) to decline, with the result that E3 (which had occurred in Scene 9 in the basic case) fails to take place, causing T8 to be noticeably lower toward the end.

In the real world, an oil embargo (as illustrated in the previous example) would call forth reactive interventions by other countries. The following case (Exhibit 6) illustrates a response by the U.S. in Scenes 2 and 3 by taking Actions 6 (law against energy waste) and 8 (R+D to promote E1 [breeder reactor]):

Exhibit 6: Action 5 in Scene 1, responded to by Actions 6 and 8 in Scenes 2 and 3

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1			1							
E2					1					
E3									1	
E4				1						
E5		1					1			
E6										
E7										1
E8								1		
E9							1			

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.2	4.4	4.5	4.4	4.4	4.6	4.9	5.4	5.7	6.1
T2	99	88	81	76	76	96	115	116	120	121	128
T3	26	33	32	34	35	34	27	30	24	17	13
T4	98	92	97	93	86	86	107	115	130	143	149
T5	99	86	88	120	139	120	161	187	194	200	206
T6	23	31	32	27	30	40	44	47	62	74	72
T7	95	90	93	98	106	125	133	149	167	188	189
T8	105	104	118	138	157	181	219	240	289	309	349
T9	19	20	24	24	22	24	27	29	29	31	31
T10	49	52	45	45	58	62	62	55	64	70	65
T11	50	49	36	29	33	38	48	59	57	68	66

The effect of the U.S. counteraction in Scenes 2 and 3 to the OPEC embargo in Scene 1, as can be seen, is to lower T5 (industrial output p-c) and raise T9 (investment) temporarily; at the same time, increased R+D toward E1 (breeder reactor) brings about its occurrence one scene earlier, resulting in an increase of T8 (energy) slightly beyond what it would have been in the basic case, i.e., without OPEC intervention or the U.S. reaction to it.

We finally turn to what may be considered to have given rise to the design of this illustrative model; that is, the need to produce a planning model that might be a constructive sequel to the Limits-to-Growth treatment of the threatening global-resources disaster. The present model, at least in principle, accomplishes this by providing the possibility of dealing with two kinds of interventions: the occurrence of certain stochastic events and the taking of deliberate actions by simulated decision-makers.

The stochastic events included in our model for illustrative purposes are E1 to E9; they occur with certain preset nonnegative probabilities. To approximate the Limits-to-Growth case, where none of them are assumed to take place, we changed all their probabilities of occurrence to zero, with the following results:

Exhibit 7: No Event Occurrences

Event occurrences: none

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.2	4.4	4.5	4.4	4.4	4.5	4.7	5.1	5.3	5.8
T2	99	88	81	78	79	93	108	103	99	100	114
T3	26	33	32	38	44	50	43	43	39	31	23
T4	98	92	93	78	66	67	84	75	72	77	79
T5	99	86	96	126	132	100	121	153	153	150	149
T6	23	31	32	28	32	40	41	39	52	65	65
T7	95	90	95	100	104	115	111	111	121	139	143
T8	105	113	119	130	141	144	163	163	195	199	234
T9	19	20	24	24	22	24	27	28	28	29	30
T10	49	52	45	45	56	58	55	50	55	61	57
T11	50	49	37	32	35	36	36	50	46	55	59

Dramatic changes for the worse from the basic case are evident. If they are not quite so drastic as the Limits-to-Growth study would have suggested, this may well be due to our relatively conservative assumptions on the effect of the occurrence of Events E1 to E9. The point is that, whatever assumptions one might wish to make regarding their influence, the type of model shown here makes it possible to examine how sensitively the outcome depends on the occurrence and interactions of the events in question and, therefore, by implication, on interventive actions initiated to affect the likelihood of their occurrence.

To conclude this paper, one more case (Exhibit 8) will be presented, which illustrates to what extent the scenario shown in

Exhibit 7 can be modified for the better through relatively modest interventions by the U.N. and the U.S.:

Exhibit 8: The basic no-events case modified by the indicated interventions during the next 20 years

Interventive actions:

Scene	1	2	3	4
Player a	A2,A3	A4,A7	A7	A7
Player b	A6,A8	A8,A12	A12,A17	A18

Event occurrences:

Scene	1	2	3	4	5	6	7	8	9	10
E1				1						
E5			1		1		1			

Trend values:

Scene	1	2	3	4	5	6	7	8	9	10	11
T1	3.9	4.2	4.5	4.6	4.6	4.7	4.7	4.9	5.3	5.6	6.0
T2	99	90	83	84	89	105	116	113	113	113	121
T3	26	30	28	35	39	44	38	38	33	27	22
T4	98	92	93	85	70	81	106	111	116	125	130
T5	99	83	96	136	143	110	132	163	171	176	180
T6	23	31	39	52	68	74	70	62	68	74	70
T7	95	90	99	108	115	129	128	131	142	162	166
T8	105	110	117	128	147	154	178	186	226	236	278
T9	19	21	24	24	22	24	27	29	29	30	30
T10	49	52	47	47	61	63	60	53	57	64	58
T11	50	48	39	35	40	46	48	55	52	64	63

As can be seen, the counteractions taken during the first 20 years (Scenes 1-4) of the 50-year period under consideration have the effect of improving all the indicators markedly (cf. Exhibit 7), to the extent of even generally exceeding the levels attained in Scenes 3-6 in the basic case (Exhibit 2).

It may, of course, be objected that this result merely is a consequence of the input numbers chosen for our illustration. So it is; yet more carefully chosen, and thus presumably more realistic, numbers are unlikely to change the outcome by an order of magnitude. In any event, I do not wish to anticipate the substantive results of a more serious planning study along the lines suggested here; my intention, rather, was to show the potentialities of a new methodological approach that permits simulated reactions by decision-making agencies to unforeseen technological, environmental, or strategic contingencies.

In particular, the "only feasible solution" presented by Mesarovic and Pestel[5] might be subjected to close reexamination by such an approach, not so much to test its validity but to determine whether its precariousness can be attenuated through the inclusion of model-endogenous interventive events.

References and notes:

1 Olaf Helmer, "Interdisciplinary Modeling", a chapter in: Churchman and Mason (editors), World Modeling, North Holland Publishing Co., 1976.

2 Meadows et al, "The Limits to Growth", Potomac Associates, 1972.

3 See H. Winthrop, "Social systems and social complexity in relation to interdisciplinary policymaking and planning", Policy Sciences 3, No.4.

4 I have listed a few of these desiderata in "An Agenda for Futures Research", Futures, February 1975, and in "Problems in Futures Research: Delphi and Causal Cross-Impact Analysis", Futures, February 1977.

5 Mesarovic and Pestel, Mankind at the Turning Point", Dutton & Co, New York, 1974.