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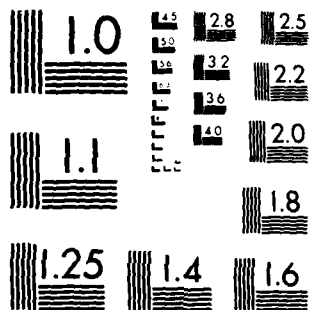
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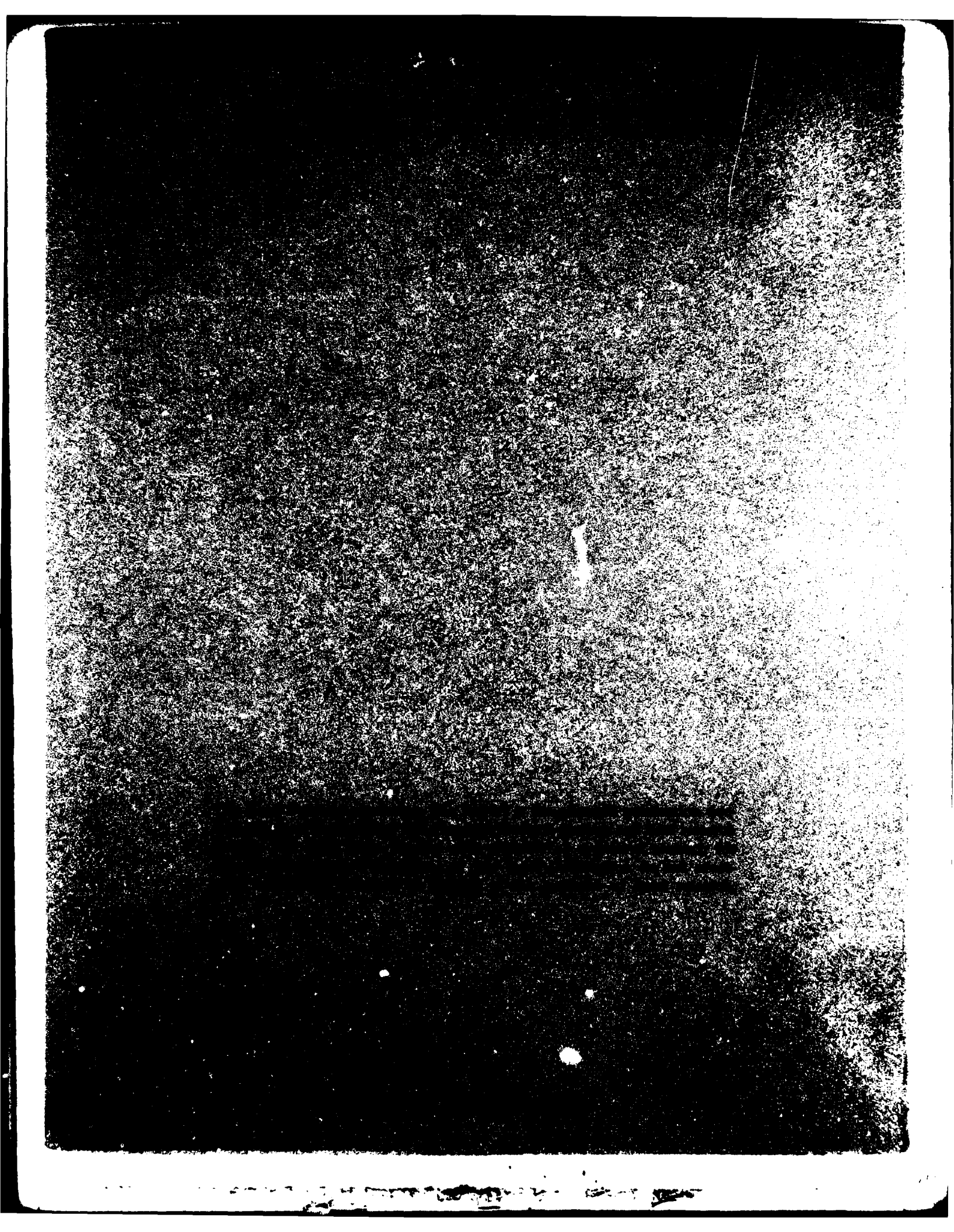
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The author of this Note speculates about the possibility and desirability of developing a formal calculus for evaluating scenarios. Scenarios are an essential element of military planning. The author argues for the need of a calculus--a rigorous method for evaluation--of the scenarios used in military planning studies. The purpose of the calculus is not to generate scenarios, but to evaluate them within some commonly shared framework or set of rules. A two-dimensional structure for evaluating scenarios is suggested as an illustration of how formal procedures might be employed to diagram a scenario, much as a sentence or electrical circuit is diagramed. A calculus of scenarios, if developed along the lines proposed in the Note, would enable the defender and critic of a scenario to reason together about its omissions, inconsistencies, and uncertainties.

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# A RAND NOTE

TOWARD A CALCULUS OF SCENARIOS

Carl H. Builder

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PREFACE

The author of this Note speculates about the possibility and desirability of developing a formal calculus for evaluating scenarios. These speculations have their origin in some of the concepts for automated gaming and scenario generation associated with Rand's Strategy Assessment Center. The Note is being published at this time and in this form to solicit the interest and intellect of others who might contribute to the development of such a calculus.

The concept of a calculus for scenarios should be of interest to those who use or write scenarios for military planning. At the least, it may help some to be more conscious of the content and power of scenarios. At best, it may encourage some to take up the quest for a calculus that will provide a common analytical framework for evaluating scenarios. And if scenarios can be made more explicit, consistent, and complete by the application of such a calculus, then military planning may become more the master and less the servant of its scenarios.



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SUMMARY

Scenarios are an essential element of military planning. They are an integral part of crisis and conflict forecasting, contingency planning, threat definition, the analysis of weapon systems, and the gaming of military operations. Because scenarios describe the future--as projected, assumed, speculated, or hypothesized--they can foreordain the results and conclusions of military planning studies. What purports to be the results of rigorous analysis may be mostly the inevitable products of the chosen scenario. Despite the extensive reliance on scientific methods for military planning studies--as reflected in the use of operations research, systems analysis, and computers--scenario development and evaluation remain an art without much discipline. Scenarios may be the last wild cards in the increasingly formalized military planning processes.

In this Note, the author argues for the need of a calculus--a rigorous method for evaluation--of the scenarios used in military planning studies. The purpose of the calculus is not to generate scenarios, but to evaluate them within some commonly shared framework or set of rules. Such a calculus does not now exist, but its various aspects can be described through several analogies drawn from the arts and sciences. Some of the concepts and language for the calculus might be found in stage plays, which share many similarities with scenarios. A two-dimensional structure for evaluating scenarios is suggested as an illustration of how formal procedures might be employed to diagram a scenario, much as we diagram an electrical circuit or a sentence.

A calculus of scenarios, if developed along the lines proposed here, would enable the defender and critic of a scenario to reason together about its omissions, inconsistencies, and uncertainties. While the calculus would not denigrate the important art of writing scenarios, it could focus arguments about the validity of scenarios and lead to their improvement, in much the same way as we now evaluate and seek to improve the quantitative analyses in military planning studies. The latency of such a calculus of scenarios is not proven; but it may be reasonably inferred in the processes of Rand's Strategy Assessment Center, where scenarios are being generated by programmed automatons.

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## I. INTRODUCTION

This Note advances a theory about the analysis of scenarios. The theory is that scenarios can be rigorously evaluated, with a rigor approaching that now used to evaluate artifacts produced from the arts and sciences. That process of evaluation might be called a calculus of scenarios. And since such a calculus does not yet exist, this Note is titled *Toward a Calculus of Scenarios*.

A calculus, as defined here, is a rigorous method for analysis. Rigor implies rigid principles or practices that can be invoked as a commonly held framework in the process of evaluation.

A scenario, as defined here, is an outline of the events leading to, and providing the context for, a situation of interest or concern. Within the military planning community, scenarios are the brief stories about possible future events we use to set the stage for analyzing or gaming a military problem.

Thus, *Toward a Calculus of Scenarios* is meant to put forward a hypothesis about the existence and possible form of a rigorous method for analyzing and evaluating scenarios, particularly those scenarios developed and used within the military planning community. The hypothesis is being put forward at this time and in this form to encourage others to consider and contribute to the evolution of the calculus, if there be one. Development and use of the calculus may require a new school of thinking; and such new schools usually reflect the confluence and interactions of many minds concerned with a common problem. In any event, the author believes that reducing the calculus

of scenarios, as hypothesized here, to a practical art is currently beyond his capabilities. He can sketch a vision, but cannot yet complete the picture.

The hypothesis was stimulated by the author's association with Rand's Strategy Assessment Center during its first phase of development. The Center has demonstrated the ability to automate the players in political-military games by using computers and advanced programming techniques. Fully automated players have the ability--more correctly, the rigid proclivity--to generate their own unique (but reproducible) scenarios, rather than following some preferred (but externally imposed) script. For perhaps the first time, we have objective means for developing scenarios. That a scenario can be generated by explicitly disciplined automaton suggests the reverse: that any scenario might be analyzed to reveal the discipline (or lack thereof) that caused its generation. The calculus of scenarios is a hypothetical device for just that revelation.

In the sections that follow, the hypothesis is developed in three steps: Section II offers reasons for wanting more rigorous methods for evaluating scenarios. It describes the various forms and uses of scenarios in the military planning community and concludes with some propositions about the importance and nature of scenarios. Section III suggests some of the characteristics to be sought in a calculus of scenarios by comparative analogies with other analytic disciplines. It introduces some fundamental structural concepts by reference to the familiar elements of a stage play. Finally, Section IV outlines one possible form of a calculus of scenarios, the process by which it might be used in evaluating scenarios, and some general specifications for its future development.

## II. THE USES OF SCENARIOS

In the military planning community,[1] scenarios figure importantly in a variety of planning activities. They include forecasts, plans, threat definition, and contexts for problem analysis and gaming. Some examples will illustrate the diversity of applications.

### FORECASTS

All plausible forecasts involve scenarios. Forecasting the outcomes of crises and conflicts, such as the Polish crisis and the Afghanistan conflicts, may range from simple guesses as to what will happen next to elaborately detailed stories, as in Hackett's Third World War. [2] However, the level of detail should not mask the presence of a scenario: in each is to be found the outline of supposed future events, which leads from the world as we know it to some forecasted outcome. Some events may be omitted and left to inference; some events may be vividly detailed in order to bring them to life or make them more credible; but whether fleshed out or stripped down, they are ultimately scenarios. And it is the scenario that carries the essence of the forecast.

Most military plans are contingent forecasts. Plans typically call for a sequence of contingent events--a scenario--if some triggering event occurs, such as receipt of warning or authorization to mobilize. To call a plan a forecast and, hence, a scenario may seem to be too

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[1]In the United States, this would include the Department of Defense, the military services, and their contractors.

[2]General Sir John Hackett and others, The Third World War, Macmillan, New York, 1978.

broad a definition; but the contingent events called for in plans are generally not completely under the control of the planner; and, obviously, that is one reason why plans sometimes fail. If a plan contains an outline of events leading to a situation of interest (i.e., satisfaction of the intent of the plan), then by the definition given earlier, that plan is a scenario.

#### PROBLEM DEFINITION

Scenarios are also used in the defense planning community to define, or to create an interest in, a problem--usually in the form of a threat. One specific example is the "pin-down" threat defined against the U.S. ICBM force in the late 1960s. The scenario involved the Soviet use of their SLBMs for high-altitude nuclear detonations over the U.S. Minuteman fields, creating an adverse electromagnetic environment that would keep the U.S. missiles pinned down in their silos until the more accurate Soviet ICBMs could arrive (20 minutes later) to dig them out. This scenario, posed as a hypothetical threat to the Minuteman missile system, required an exquisitely orchestrated sequence of events involving coordinated ICBM and SLBM attacks by the Soviets and U.S. decisions to launch or withhold its ICBM force. Initially, the scenario was intended to attract interest in a novel form of system vulnerability. Ultimately, the scenario defined the technical requirements for electromagnetic hardening (protection) of the Minuteman missiles.

Other examples of scenarios for threat definition are found in the studies and analyses of proposed M-X basing concepts. These scenarios typically hypothesize the optimum development and employment of ballistic missiles and space surveillance systems by the Soviets to

attack M-X missile basing systems. Some of these scenarios require precursor attacks to unmask deception devices, followed by space surveillance to locate the M-X missiles, followed by another wave of attacks to destroy the missiles themselves. These scenarios are often called worst-case threats because they generally assume maximum information for, and exploitation by, the Soviets, coupled with minimum information for, and reaction by, the United States. They are specifically tailored to the perceived vulnerabilities of a particular basing concept and are then used to imply the performance requirements (threat) that the proposed basing system must meet. Performance requirements for ballistic missile defenses have also been posed in scenarios tailored to provide worst-case threats.

#### ADVOCACY

Sometimes such worst-case-threat scenarios are developed by those advocating a particular concept, who then use them as an a fortiori proof of the performance adequacy of their concept. The assured destruction criterion, which has been used since the early 1960s to measure the adequacy of U.S. strategic forces, contains such a scenario: The Soviets are assumed to carry out a maximum surprise attack upon U.S. strategic forces in their peacetime (minimum) alert posture. The surviving U.S. forces are then measured in their ability to destroy an adequate fraction of the Soviet population and industry. If adequate for this worst case, it is presumed that they are also adequate for all lesser cases. This scenario was first posed as part of an argument against any further increases in U.S. strategic forces: The worst-case threat provided an a fortiori proof that the then-current forces were adequate. Of course, what the proof left untested was the scenario



itself: whether all other cases are certain to be lesser and included, even when the adequacy of the forces was to be measured solely in terms of their capabilities for deterrence.

Worst-case-threat scenarios, unfortunately, sometimes find their way from adequacy tests, where their use can at least be logically justified, into comparative performance analyses for weapon system selection, where they may only serve to skew the comparisons. An example here is worth some detail, for it will illustrate both that point and, in Section IV, the evaluation of scenarios with a hypothetical calculus.

#### AN EXAMPLE SCENARIO

During the late 1960s, analyses supporting advocacy of the advanced strategic bomber (first as the AMSA, later as the B-1) devoted considerable attention to the problem of bomber prelaunch survivability against the threat of SLBM attacks on the bomber bases. The scenarios typically[3] contained the following elements:

- o Some number of Soviet missile-firing submarines would take up optimum locations off the coasts of North America for surprise attacks on all U.S. bomber and tanker bases. The locus of their positions would be at some minimum distance or water depth off shore. These lines would extend along both the Atlantic and Pacific Coasts, often including the Gulf of Mexico, sometimes including Hudson Bay.

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[3]For an example, see James A. Winnefeld and Carl H. Builder, "ASW--Now or Never," To Use the Sea, 2nd. Ed., Naval Institute Press, Annapolis, Md, pp. 121-127, 1977.

- o At a prearranged time, the Soviet submarines would carry out a simultaneous and coordinated attack, launching their missiles at the maximum estimated firing rate along trajectories designed to minimize warning time. The missiles would be MIRVed,[4] targeted, and fused so as to minimize the number of escaping aircraft at each base, taking into account the distance of the base from the submarine, the number of aircraft at each base, and their takeoff rates, flyout speeds, and directions.
- o The bombers and tanker aircraft, optimally deployed and variously postured on routine and generated alerts, would be launched on receipt of attack warning, taking off at minimum intervals, and flying out at altitudes, speeds, and directions to minimize their vulnerability to pattern barrage attacks on each base.

Even a cursory reading of the above three elements indicates how these scenarios were framed to set up some elaborate optimizations. Both the attacker and defender were free to optimize several parameters in their respective efforts to minimize and maximize aircraft survival. Those simultaneous optimizations involved computer codes that taxed the mathematics and computers of the day.

The results of such studies invariably showed that the faster aircraft (i.e., the B-1) was more survivable against these kinds of attacks. But once engaged by the complexity of the calculations and the elegance of the min-max solutions, it was easy to forget how the

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[4]That is, fitted with Multiple Independent Reentry Vehicles.

scenario provided for the context and, ultimately, the worth of the answers. The calculations, while mathematically admirable, obscured the scenario that drove the answers. The results were not so much the product of the calculations as they were the inevitable consequence of the scenario. Yet the calculations were subject to great scrutiny, while the scenario went almost unchallenged. The questions of the day were whether or not the computer codes were yielding true min-max solutions, when they might better have been whether the scenario had sufficient credibility to warrant any interest in the analytic results. Similar observations could be made about some of the elaborate computer-based studies of ballistic missile defenses, bomber penetration through air defenses, etc.

#### GAMING

Finally, scenarios are used in the military planning community to provide a context for the gaming of crises and conflicts. Scenarios are always used to provide the initial conditions or setting for games. In the absence of a scenario, a game would have to begin with conditions as they exist today and are understood by the game participants. Changing those initial conditions and insuring their common understanding by the game participants requires some kind of scenario.

In addition to setting the context for games, scenarios can focus the game activities. Scenarios can be invoked at the beginning or at critical stages of a game to insure that the participants address the purposes of the game--whether they be training, education, issue exploration, option development, etc. When scenarios are used to focus the game activities, it is important to remember their influences on game outcomes. An example will illustrate the point.

Several years ago, before the fall of the Shah of Iran, the author sponsored a game at Rand aimed at exploring U.S. options for military intervention in the area of the Persian Gulf. Before the game, the game director properly asked about the purposes of the game. The largest team, representing the Joint Chiefs planning staff, was to be put through the paces of planning at least three levels of military intervention: (1) resupply of indigenous forces, (2) insertion of supporting forces, and (3) commitment to ground combat. With that specification of purposes, the game director developed initiating scenarios that fairly invited the first level of intervention and then, by his direction of reasonable control team actions in subsequent game moves, he sequentially provoked the other two levels of intervention. In analyzing the results of the game, it was essential to separate the events that had been deliberately programmed into the game by the scenarios from those events that were the spontaneous and unexpected responses of the players.

#### SOME PROPOSITIONS ABOUT SCENARIOS

The foregoing perspectives of the uses of scenarios in military planning can be summarized in the following propositions about their roles:

- o At the heart of all military forecasts, plans, and threats are scenarios.
- o The worth of an analytical study is more likely to be found in its scenario than in the quality of its arithmetic.

- o More often than not, the scenarios used in analytical studies foreordain the analytical results.
- o Control of the game scenario is tantamount to control of the game outcome.

These four propositions suggest that scenarios are pervasive and can be used manipulatively in military planning. The patina of science, analysis, and computers in military planning can easily obscure the powerful role of the scenario in defining the problem and bounding its solution. An appropriate, albeit harsh, caution might be:

- o If you buy the scenario, you buy the farm.

### III. WHAT IS A CALCULUS OF SCENARIOS?

#### ANALOGIES FOR THE CALCULUS

Defining a calculus of scenarios before the fact is something of a paradox: To define it directly would be to have it in hand. The best that can be done here is to suggest what it might be by way of analogy. No single analogy captures the idea completely, but several different analogies may illustrate different aspects of the calculus sought here-- what we ought (and ought not) expect from it.

The first analogy is taken from the field of aeronautical engineering, where the analogous calculus comes from the laws of physics. Suppose the question was:

What should an airplane look like?

The laws of physics would be of little help in answering that question. To be sure, physics limits the latitude of aircraft designs, but not very much: They all have wings of a sort and engines; but beyond that, they come in large and small sizes, with stabilizers fore and aft, with propellers and jets, with one to eight engines, with one or two wings, straight or swept, etc. While the laws of physics limit the designer in some arrangements and proportions, the marvelous diversity of aircraft tells us that those laws do not begin to define the answer to the question of what airplanes should look like. The

designer has considerable latitude for creative answers within the calculus.

Given that we knew what an airplane was to look like, suppose the question was:

How should an airplane be built?

Here, the laws of physics are more helpful; but considerable latitude still exists. Physics may dictate material qualities and quantities, but the designer retains the freedom of choice in materials and structural concepts: Wood and fabric may still compete with aluminum. Bulkheads and stringers may attract one designer, while stressed-skin structures appeal to another.

Given that the airplane is built and sits upon the ground, suppose the question was:

Will it fly?

Now the laws of physics become a powerful arbiter. If we disagree in our intuitive judgments about whether or not the airplane will fly, we have a rigorous, commonly shared set of rules to conduct a systematic evaluation. In principle, we should be able to calculate the forces acting on the aircraft and determine its motion in flight. While our

measurements or arithmetic and, therefore, our conclusion may be in error, we at least share a common framework for our inquiry into the question. It may be that the laws of physics take us only to a point where our differences in judgment are focused on some smaller, unresolved issue (e.g., estimates of the drag coefficient); but the laws remain as a framework for others to enter the debate and to help us resolve our differences (e.g., conducting wind tunnel tests).

Obviously, it is this last question that sets up an analogous situation for a calculus of scenarios: Given the existence of an airplane (scenario), do we have a suitable calculus for evaluating its ability to fly (its integrity)? While the calculus will not design (write) the airplane (scenario), it is a rigorous tool for evaluation.

The second analogy is taken from the field of literature, where the analogous calculus might be the rules of grammar. Suppose the question was:

Is the manuscript literary art?

Here, the rules of grammar are of almost no help to us. The writing may deliberately violate the rules of grammar and, yet, the manuscript may represent outstanding literary art.

Suppose the question, instead, were:

Is the paragraph good exposition?



The rules of grammar may be of some limited help in this case, at least to the extent that exposition is impaired by weaknesses in grammar. But poor exposition is more likely to be a failure of thinking than of grammar; fuzzy thinking can be conveyed in impeccable grammar. [1]

Finally, suppose the question was:

Is it a correct sentence?

Now the rules of grammar become powerful tools for evaluation. We can diagram the sentence using established formalisms, identify the usage of words in the sentence, and check the sentence for completeness, consistency, structural clarity, and form. While there remains some latitude in the choice of words or their arrangement, and considerable room for doubt about the content of the sentence, the question of grammatic correctness can be approached objectively with a well-established set of rules.

Again, the last question comes closest to the analogous situation for a calculus of scenarios. If the sentence (scenario) exists, do we have a set of tools for diagramming and identifying its components and then checking it for completeness and consistency? Those tools may not define which sentence (scenario) to write; nor will they define the only

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[1] There are some experimentally supported rules for good exposition that can be applied to paragraphs; but I have limited the analogy here to the rules of grammar, which are much more widely appreciated.

way to write it; but given its reduction to writing, those tools become a rigid bridle or harness for its evaluation.

Still another analogy might be found in musical theory, where there are quite definite rules for the composition of music. On the basis of such theory and the rules that flow from it, it is possible to compose and arrange music by means of computer programs. While deliberate violation of these rules is not uncommon for creative effects, such violations are apparent and do not detract from the validity of the theory. Musical theory alone, of course, does not write great music, perhaps not even good music. But it can certainly help in the writing of good music and in evaluating what may be wrong with bad music.

By analogy, then, the calculus of scenarios is not a discipline that will create scenarios. The development of scenarios, like the design of airplanes and the writing of literature, is likely to remain, ultimately, a highly creative human act. Machines and disciplines may very well assist in those creative acts; they may even pretend to perform them; but the human mind will prevail in their instigation and conception, if not their execution.

Also by analogy, the calculus of scenarios will not tell us whether or not a scenario is useful or compelling. Those will and should remain subjective judgments; they are matters worthy of argument and the test of audience reaction. But we should not be left to argue without discipline about whether a scenario is complete, consistent, or explicit. For that, we should have a calculus of scenarios. As with the laws of physics or the rules of grammar, we need a set of well-established, shared principles we can invoke together to insure the technical adequacy, but not the artistic qualities, of scenarios.

### SCENARIOS AS STAGE PLAYS

Some of the concepts and nomenclature for a calculus of scenarios may be found in the similarities and contrasts of scenarios and stage plays: Scenarios, like stage plays, have authors and scripts. Authors generally have a purpose in their script. Is the play intended to provoke or to educate its audience; or is it simply to amuse? Does the playwright want to make a statement or convey a social message? Does he want his purposes to be apparent or subliminal? Critical review of plays takes into account these apparent or assumed purposes of the playwright. Likewise, scenarios are written for purposes (such as those outlined in Section II); and those purposes should guide the application of a calculus. A scenario used as a forecast might properly be evaluated by different standards or expectations than one used to define technical requirements for system development.

A playwright uses a stage to focus the audience's attention and scenery to provide a context or background for the stage events. These same elements can be found in scenarios. The playwright neither wants nor is able to put the entire world into his play. The stage is a way of bringing that portion of the world he wants the audience to deal with into focus; the rest of the world is assumed to be understood, existing off-stage. Scenery, when used, helps the audience orient itself to the stage events and enhances their credibility or reality. The scenario writer, too, neither wants nor is able to treat the entire world in his scenario. Frequently, after setting the background (scenery) of the world condition, the scenario writer focuses on a particular part of the world (the stage) and upon the actions of a few countries, governments, or agencies.

The playwright's greatest concern is with the actors in his play-- the development of their character and then the portrayal of their behavior as they interact with each other and with outside events. The critical review of a play generally includes comments on the development of the characters and the plausibility of their actions. For scenario writers involved in military planning, the actors are most often countries, governments, or agencies; and their character, unfortunately, is frequently presumed rather than developed. For example, scenario writers often proceed as if everyone knows and agrees on the character of the Soviet Union; and given that character, assume that the behavior they ascribe to the Soviets in their scenario is consistent and plausible.

Both plays and scenarios portray chains of events. These events are of two kinds: acts of volition and acts of nature. The actor who points a gun at another on the stage is portraying an act of volition. When he pulls the trigger, he also portrays an act of volition. But when the gun fails to fire, that portrays (or is) an act of nature. If he pulls the trigger a second time and the gun fires, we have sequential acts of volition and nature again. In scenarios for military planning, the decision for one nation to attack another is an act of volition, but the expected failure of some fraction of the missiles, due to unreliability, is an act of nature. The difference between these two kinds of events may provide an important structural distinction for a calculus of scenarios.

IV. HOW COULD A CALCULUS OF SCENARIOS BE USED?

A STRUCTURE FOR THE CALCULUS

How could we diagram a scenario--in the same sense as we now diagram a sentence, an electronic circuit, or a steam plant? How can we geometrically arrange the components of a scenario in a way that shows their logical relationships? Such diagrams are typically two-dimensional, so we should begin by looking for two dimensions that contain or portray important aspects of a scenario.

If a scenario is an outline of events--a chain of events--then one dimension of a structure could be time.[1] Time is a dimension of a stage play: the events (actors lines and stage actions) follow one after another in their time sequence. Thus, a scenario could be broken down into a sequence of events that are arranged in the order of their occurrence in time.

A second dimension could be the kind of event--whether it represented an act of volition or an act of nature. By separating events into these two categories and arranging them along a time line, we could have a structure like that shown below--a structure that could, in principle, isolate and logically arrange all events that compose a scenario.

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[1]Major Sherry Sims, USAF, suggested this dimension while describing scenarios as a chain of events, each event consisting of an input, a decision, and an output.

Acts of Nature -----	Time -----	Acts of Volition -----
N1	Event 1	V1
N2	Event 2	V2
N3	Event 3	V3
	.	
	.	
Ni	Event i	Vi

With reference to the diagram, the first event in the scenario, Event 1, might be composed of a single act of volition, V1 (e.g., the Soviets decide to launch an attack on the United States), or a single act of nature, N1 (e.g., the Soviet wheat crop fails). Either V1 or N1 could be null; but both could not be--else there would be no event. Either V1 or N1 could involve simultaneous, multiple acts of volition or nature. For example, N1 could be the failure of the Soviet wheat crop and a bountiful U.S. harvest; V1 could be simultaneous alerting of strategic forces by both the Soviets and the United States. The second event of the scenario, Event 2, would be the next immediately following (proximate) event in the sequences that ultimately compose the scenario. Each event in the chain establishes a new state of the world, derived from the previous state of the world, but modified by the acts of nature or volition that make up that particular event. Thus, a scenario can be seen as a chain of transition events that result in a continuously changing state of the world.

Even this rudimentary diagram provides a structure for evaluation: First, looking at the chain of events, where does Event 1 start the scenario? Event 1 must occur in some setting. Does it occur at some future point in time? If so, is that future world different from the present world? How? What events transpired to make it so different? Are we entitled to examine those events? Should such events be a part of the scenario?

Thus, one of the first principles (or laws) that might emerge from a calculus of scenarios is that all scenarios must start with today's world. Otherwise, the chain of events has been truncated so as to begin in a future world that is not defined. To define a future world is to imply some chain of events that created it. That implied chain of events ought to be subject to the same opportunity for examination as the explicit events outlined in the scenario. Describing the state of a future world is not the same as describing the events that brought that world about. The state of a future world may seem plausible; but it may be very hard to find a credible sequence of events to bridge the distance between today's world and that future world. The path to a future world is an integral part of that future world.

The scenario used for submarine-launched missile attacks on U.S. bomber and tanker bases, described in some detail in Section II, provides a good example of a violation of this "first law." That scenario begins with Soviet submarines located in optimum positions close to the U.S. coasts. While that is physically possible, it describes a future world rather than the present. Bridging those two worlds with a complete sequence of plausible events is a frustrating

task. Very quickly, one is drawn into questions of submarine detection and vulnerability, aircraft dispersal options, political reactions and consequences, etc. This is not to say that such a bridge cannot be built; but when it is built, it then becomes evident that the events of the bridge are the important ones worthy of analysis--not the truncated set included in the scenario.

Where should the chain of events be ended in a scenario? The same example scenario is truncated in its ending--it ends with the surviving aircraft leaving behind the mushroom clouds of the Soviet attack and proceeding toward their targets. Presumably, the Soviet attack had some purpose (implied, but lost, in the truncated events from the front of the scenario). Would that purpose have been accomplished if we could trace the subsequent chain of events? If the rest of the scenario, rather than being left implicit, was explicitly extended toward war outcomes, which would be the most interesting part--the original truncated scenario or the the chain of subsequent events?

For practical reasons, the chain of events in a scenario cannot be unlimited. Truncation, as in a stage play, is necessary and helpful. Like the editing of film, it can be a creative contribution in scenario writing. But truncation is a two-edged sword; it can be used equally well for drawing and suppressing attention to issues. The calculus of scenarios should not be the arbiter of which issues deserve attention; rather it should provide a structure that identifies truncations and legitimizes demands upon the scenario's author to provide the missing events and to defend their plausibility.

The simple separation of events into acts of nature and acts of volition also provides a structure for evaluation: Acts of nature arise



within the natural domains--in space, in the atmosphere, in and on the sea, etc. When the scenario writer invokes an act of nature, a number of questions arise: Is the act consistent with our knowledge of the laws of nature? Has the author invoked statistical improbabilities in his scenario? Does an act of nature arising in one domain affect other natural domains? Are all of the affected natural domains accounted for?

Obvious examples arise with the use of nuclear weapons. The decision to use nuclear weapons and to push firing buttons (or turn keys) are acts of volition. But, given those acts of volition, the detonation (or failure) of a nuclear weapon is an act of nature. When nuclear weapons are used in or on the sea, they significantly alter the acoustic environment upon which most underwater sensing depends. When nuclear weapons are used in space, they can alter the electromagnetic environment upon which most aircraft and space systems depend for communications and navigation. The calculus of scenarios should provide a structure that makes scenario writers accountable for the reactions in all affected natural domains. When he invokes the use of nuclear weapons in conflicts on the sea, he should be obliged to account for what is happening under the sea as well.

Acts of volition, in scenarios as in stage plays, are much more complex. The number of actors to be accounted for is theoretically as large as the number of people in the world. Obviously, the scenario writer truncates the number of actors to some relevant, manageable number. The calculus of scenarios should permit us to identify the truncation of actors and make the scenario writer accountable for the actors who have been left out. What are the criteria for truncating the list of actors? Have all the critical actors been accounted for?

In scenarios, unlike stage plays, actors are often aggregated into factions, agencies, governments, and countries (e.g, the PLO, SAC, the Kremlin, France). Since these aggregations are actually composed of individual actors, it may not be valid to treat them as a single entity for some acts of volition. The calculus of scenarios should identify these aggregations and invite an evaluation of their actions as single entities.

The calculus should also call attention to the character, expressed or implied, of these actors. Is an act of volition (behavior) ascribed to a particular actor consistent with the character--as described by the scenario writer or as implied by the actor's behavior elsewhere in the scenario? The structure suggested here could provide a framework for checking the consistency of behavior of a particular actor at each link in the chain--from Event 1 to Event i. Although actors need not behave consistently--in stage plays, scenarios, or the real world--the scenario writer should be held accountable to explain to his critics those inconsistencies in behavior he has assigned his actors.

Thus, the structure for a calculus of scenarios might be a linear chain of events, beginning with today's world, and marching incrementally through a series of future worlds, with each increment marked by one or more acts of nature and acts of volition. The acts of nature and volition might be arrayed to invite comparisons with other acts--prior or subsequent in time--as a basis for checking the consistency of behavior. The acts might be internally diagrammed or structured to invite checks for truncation of natural domains or actors and for aggregations of actors.

Obviously, there is some uncertainty as to the state of today's world, let alone future worlds: We do not know or even agree about everything that is going on. We may not agree on some of the laws of nature that govern today's (and future) worlds. An important function of the calculus of scenarios should be the identification of those uncertainties. If we start out with different, but unstated, perceptions of today's world, we may be in unequal positions with respect to the plausibility of a scenario. We may find ourselves arguing about the scenario, when, in fact, our differences take root in our implicit views about the real world. The calculus of scenarios must help us to identify these differences as an integral part of evaluating any scenario.

#### APPLYING THE CALCULUS

If the calculus of scenarios existed as envisioned here, how might it be applied? In the absence of the calculus, the answer is necessarily speculative. But the speculations as to how it might be used may shed additional light on the concept and capabilities of the desired calculus. What follows here are four hypothetical steps in the application of the calculus to a scenario.

The first step would be to have the scenario reduced to a narrative. As with the diagramming of a sentence, first, we need to have the sentence written down where more than one person can look at it. Reducing the scenario to writing need not take any particular form. If the calculus is to have general utility, it should be capable of being applied to any scenario--no matter who writes it or what the form of the narrative. It should, of course, be as complete and explicit as the scenario writer can make it.

The second step would convert the written narrative into a set of formal statements. This step might be analogous to converting a narrative argument into a set of logical propositions. The practitioner of the calculus would be able to detect the elements of the calculus within the narrative, extract them, and construct a series of formal statements intended to be the equivalent--except in form--of the original narrative.

The formal statements, like logical propositions, might look awkward and stilted; but they should be understandable to the uninitiated, for their purpose would be to insure a common interpretation of the original scenario. Both the scenario writer (defender) and calculus practitioner (critic) should be able to understand both the narrative and the formal statements and to jointly approve the translation from one to the other. The scenario writer should be able look at the formal statements, recognize within them his scenario, and only grumble that they seem to be an awkward way of expressing the content of the narrative. The calculus practitioner should be able to look at the narrative and assure himself that he has extracted all of the relevant content of the scenario and converted it into the formal statements needed to apply the calculus. If there are differences of interpretation between these two, they should be apparent and corrected at this step.

The third step would convert the formal statements into some kind of diagram. Here, rigorous rules would be used to take the content in each of the formal statements and place it within a comprehensive structure-- something like a matrix or fault tree--where each element

has a proper place and all elements can be accounted for. The structure would be neutral--like the diagramming of a sentence. It might show omissions, duplications, or contradictions on its face; but such problems would be directly traceable to the formal statements and, hence, to the scenario narrative.

Given the diagramming of the scenario, the fourth and last step would be to evaluate the scenario with reference to its structure. If the structure is adequate, the scenario could be checked for truncations, inconsistencies, and uncertainties. The scenario described in Section II for analysis of bomber prelaunch survivability against SLBM attacks can provide some examples of what the calculus might turn up when used for this kind of evaluation.

The truncations to be checked would be in the chain of events (important missing events before, after, or within the scenario), natural domains (important collateral effects neglected), and actors (important actors omitted). In the example scenario, the important missing events would include those leading up to the submarines taking their optimum positions along the coasts and those after the bomber bases had been attacked. Did the submarines sneak in undetected? What happened in the war after the bomber bases were attacked? If those missing events had been credibly developed (and it might have been difficult to supply a credible chain on either side of the events included in the scenario), they would probably raise far more interesting and lucrative issues for military planning than the one for which the scenario was used.

The important collateral effects neglected in the example scenario could include the civil damage produced by SLBM attacks on all of the

bomber and tanker bases, particularly when they involve optimized barrage patterns to catch the escaping aircraft along their flight paths. Are the civil fatalities likely to be too high for the attack to be considered limited or military in its objectives (i.e., would they be enough to make the differences in aircraft survival irrelevant by comparison)?

The only actors in the example scenario appear to be the commanders of the attacking and targeted forces. While all possible actors need not (cannot) be considered, there are some important actors omitted from this scenario. What is the U.S. Navy, particularly its ASW forces, doing about the Soviet submarines along the U.S. coast? What is the U.S. government saying to its Soviet counterpart? Has the United States responded by sending all of its available SLBMs to sea, thereby more than offsetting the differential losses in aircraft?

The inconsistencies to be checked in the evaluation process include how the scenario treats acts of nature and volition. The example scenario does not offer any obvious inconsistencies, but some are conceivable. With respect to acts of nature, it might be inconsistent to assume that the Soviet SLBMs are fired from an ice-free Hudson Bay while the aircraft takeoff times include winter icing delays (i.e., summer and winter occurring in the same area at the same time). With respect to acts of volition, it would be inconsistent to assume that the aircraft force commander would develop elaborate tactics for the escape of his aircraft from SLBM attack, but would not insist upon their dispersal to civil and out-of-country airfields if he became aware of optimal submarine deployments for such an attack.

The uncertainties to be checked include the laws of nature, the character of actors, and the state of the world. In the example scenario, with respect to the laws of nature, there is uncertainty about how aircraft will respond to the natural environment created by barrage patterns of nuclear weapons. In some analyses, this uncertainty was handled by parameterizing the aircraft vulnerability. With respect to the assumed character of the actors, there would seem to be considerable room for uncertainty about the passivity of the aircraft force commander and boldness of the submarine force commander. And with respect to the state of the world, the example scenario invites a discussion about the uncertainties that attend U.S. abilities to detect and track Soviet submarines, the reliability of SLBM attack warning, and the performance of Soviet SLBMs in a simultaneous and coordinated attack. It would not be surprising to find that the uncertainties attending reliable attack warning are more important than the calculated differences in aircraft prelaunch survivability, insofar as they determine the overall U.S. capabilities for retaliation.

Having said all this by way of evaluating the example scenario, why does one need a calculus of scenarios to conduct such an evaluation? The answer is simple: In the absence of an agreed calculus, there is little assurance that the above evaluation is systematic or, more importantly, that the defenders of the scenario would accept the pertinence of these questions. To provide the basis for a dialog and a comprehensive evaluation, we need something more than we have now.

This evaluation would be no better than the minds conducting it. The calculus, by itself, would not insure a good or even a thorough

evaluation. It can only provide the discipline by which both the critic and the defender of a scenario can hold onto it and focus their arguments. The analogy from aeronautical engineering used in Section II can be used to illustrate the point: The laws of physics do not assure that the evaluation of an airplane's ability to fly is correct. The evaluator may make an incorrect measurement, omit an important variable, or make an error in arithmetic. The laws of physics only provide the discipline within which several people can approach the question with common rules for reasoning, discover the variables, and then focus their differences. And so it should be with the sought-for calculus of scenarios.

#### SPECIFICATIONS FOR THE CALCULUS

By way of summary, what are the specifications for the calculus envisioned here?

First, the purpose of the calculus is to evaluate--not develop--scenarios used in military planning and analysis. The calculus should be a widely accepted set of rules that will assist in clarifying and arbitrating the contents of a scenario. The calculus should be neutral with respect to the quality of a scenario; it should not (cannot) determine whether or not a scenario is good or useful; those qualities are relative, not absolutes. But the calculus should identify the omissions, inconsistencies, and uncertainties in a scenario, whether or not they were intentional or contributive.

Second, the calculus should provide a comprehensive structure for evaluation. It should apply equally well to book-length narratives and to terse lists of analytical assumptions. It should serve as the framework for evaluation--not as the evaluation itself. The user of the



calculus must provide the evaluation; and the quality of that evaluation depends upon what the user brings to it and looks for. Thus, the calculus should be a flexible framework and set of rigid principles for using that framework in evaluation. The framework should be open ended with respect to scenario purpose, scope, detail, and form.

Third, the calculus should be a shared concept. It should translate clearly and logically from the original scenario to an evaluatory structure and back again, so that omissions, inconsistencies, and uncertainties can be traced and addressed at all levels within the calculus. Ultimately, the calculus is a tool for joint reasoning, as are the laws of physics. We may jointly use the laws of physics to evaluate whether an airplane or bird will fly. But those laws do not make either of them fly. The hawk knows nothing about the laws of physics, but flies very nicely. The hawk has no need to reason with others about the feasibility of flying (or anything else, for that matter). But, as reasoning creatures, we need frameworks within which we can reason and communicate. And that is why the calculus of scenarios must be a shared construct.

Finally, the calculus of scenarios should be more science than art. The writing of scenarios and their evaluation, at the core, will and ought to be art. But the bridge to the evaluation of scenarios should be objective science--a common framework that will not allow either scenarios or their evaluation to be simply dismissed as a matter of artistic license, yet never denying the creative power and contribution of that license.