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Matrix Games as Operations Research Tools

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Operations Research Tools by Ben Taylor

This chapter considers the utility of Matrix Games as tools for Operations Research[1] (OR) analysts. It assumes that the reader is familiar with the design and execution of Matrix Games, based on the earlier chapters of this volume.

Introduction

OR is perhaps best understood as the use of rigorous, scientific methods to support decision making. Many definitions of OR exist and they can be found in text books or in the publications of the learned societies that exist in the field. The interested reader may wish to refer to the International Federation of Operations Research Societies[2] for further information on OR and national societies. Those specifically interested in the defence and security domains will find much of interest on the site of the United States-based Military Operations Research Society[3].

The term OR was first used in 1938 to describe work being undertaken to analyse the early warning system being built in southern Britain using the then new radar technology. OR groups made significant contributions to British Commonwealth and American operations during the Second World War. Subsequently the discipline was employed across public- and private-sector organisations world-wide. A brief history of OR from the first use of the term to the present can be found on-line[4].

This chapter will not prescribe the scope and boundaries of OR, but rather will explore the utility of the Matrix Game as a tool for OR practitioners. However, it is first necessary to look at little closer at how OR is employed and the types of activities and methods that OR analysts employ.

General Approach to OR

A vast range of problems can be, and are, tackled by OR analysts. They can range in scale between something that a single analyst undertakes in a few hours to major studies occupying large teams lasting years. However, the essence of the research is usually very similar and aligns to a simple pattern. .

The client for an OR study usually seeks to improve the performance of a system. System in this instance can be taken in its broadest sense; it could be a retailer's logistics system, an airline's maintenance system, a health authority's system for prioritizing patient care, a family's system for getting everybody to their daily activities and home again or the system for detecting and responding to hostile aircraft crossing your national border. All of these types of problem are amenable to study, and indeed have been addressed by OR analysts. In each case the analysts need to work closely with the client, firstly to define what the subject system is and secondly to understand what they mean by *better*. For example; with an air defence system are we just looking at detecting and tracking incoming aircraft, or are we also looking at our ability to intercept those aircraft as well? The latter problem requires the analysts to understand and manipulate a much more complicated system than the former, because it includes more organisations, processes and types of military equipment.

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[1] The terms Operational Research and Operational Analysis are also used is some communities for the same discipline

[2] www.IFORS.org, accessed 22 December 2016

[3] www.MORS.org accessed 22 December 2016

[4] https://www.theorsociety.com/Pages/Society/SocietyHistory.aspx, accessed 16 June 2017

The objective for the study, in other words the meaning of better, can take many forms. For a grocery retailer better might mean reducing the likelihood of products being out of stock in their retail outlets; it might be to minimise the amount of produce that is spoiled in transit; or it could be simply to reduce costs while keeping the price and availability of products the same for the customer.

Having defined the problem, the analysts create a model to understand how the system works and why it performs as it does. There are many types of model, and some will be discussed in the next section, but they all share the common characteristic of being a simplified representation of reality that analysts can use to develop understanding. A model of a system will allow analysts to predict how the system will perform in the future if no changes are made.

Based on the understanding derived from creating and employing the model, the analysts develop courses of action to change the system. These can be evaluated using the model to see what consequences they might have and how much better, or worse; the system will perform if those courses of action are followed. Again, the nature of these changes will be context specific. They might include moving staff between different units of a hospital, changing the make-up of the fleet of trucks used to deliver merchandise to a retailer's stores or considering a number of candidate fighter aircraft to add to a nation's air force.

Analysts who have properly understood the client's problem and who have employed appropriate techniques to gain insight into potential courses of action open to the client are now in a position to report their findings. They present the client decision maker or decision-making body with an analysis of the options available, the risks and consequences associated with each and recommendations backed with evidence.

Properly executed OR helps the client make evidence-based decisions. At one level the OR analyst could be considered to be building and testing Matrix Game arguments. They describe a course of action, outline the consequences of adopting that course of action, and explain the reasons why the course of action will lead to the consequences. In addition, they may be able to estimate the probability of the consequences (positive or negative) occurring. We will return to this parallel later.

Models for OR

It is rare that analysis of a complex system can be undertaken using the real system directly. In some applications the system is just too large or is in constant use to be able to experiment with it. For example, there would be little public sympathy with shutting down a city's public transportation system in order to experiment with new routes and schedules. In the defence and security domain there is also the added challenge that planners seek to improve capabilities that they hope never to employ and whose capabilities they may wish to conceal from potential adversaries. There is also a matter of cost. Exercises and rehearsals with real people and equipment typically cost far more money and cause far more disruption than an analytical study conducted on a computer or a sheet of paper. As a result, OR analysts usually employ a model of the system that they are studying in order to understand its behaviour and to evaluate changes.

The scope of the term "model" is very broad in OR. It includes models that exist only in the *mind's eye*. Thus, historians can develop mental models of how past conflicts unfolded, or foreign-policy subject matter experts can offer advice based upon their mental models of how the political conflicts within a region are likely to unfold. Indeed, business leaders conducting structured brainstorming events to develop new strategies are in fact sharing and refining their mental models through the conduct of the exercise.

Some types of more formal model are identified below:

Analytical models

It may be possible to reduce the system to a series of mathematical expressions. For example, we can model the stock levels in a warehouse if we know the pattern by which stock arrives and the pattern by which it is requested. Even if the frequencies of arrivals or withdrawals, and the size of each arrival or withdrawal, are known only as statistical expressions it is possible to develop equations that can inform decision makers of the likelihood that there will be insufficient stock to meet a request or insufficient space to store an arriving delivery. These kinds of models work well for systems that can be predicted; typically, that means systems in which human decisions or choices are not a key part of the performance of the system.

Constructive simulations

If the subject of analysis is too complicated to represent the system using simple equations, but yet the behaviours of the constituent parts are predictable, then analysts can build computer simulations to study how the system behaves. The warehouse example above could also be built as a simulation, with stock levels changing through time as stock arrives and departs. Simulations can be made of conflict situations as well, provided that the simulation has a built-in plan for what each side will do or an artificial intelligence system so that the plans will adapt automatically as the simulation runs. Such simulations may be seen as computer games that play themselves. These can be useful as analytical tools, but have no recreational value.

Human-in-the-loop simulation (or game)

A simulation in which the role of decision makers is played by actual people making decisions can be termed a *game*. There are of course very many forms of game of varying scale, scope and complexity. They all share a number of important characteristics when compared to a closed simulation with no human players.

- *Firstly*, players will usually adapt to what they see going on rather than strictly adhering to strategies set out prior to the start of the game.
- *Secondly*, players can tell you what they were thinking and what they thought was going on throughout the game.
- *Thirdly*, different players, or even the same player on a different occasion, will make different decisions in the same situation.
- *Fourthly*, players will learn, and even if asked to play the same game again are likely to avoid previous mistakes if they can and to attempt to perform better on a subsequent replication of the game.

It can be seen from the above that a game is critically dependent upon the performance of the human players. An analyst running a game may get valuable and insightful feedback from the players that could never be produced by an automated simulation. However, that simulation is not subject to the personalities, moods and simple rich human diversity that players bring[5].

Within the professional analysis community there are clear pros and cons of the two approaches.

[5] Of course, there are occasions where exploring unforeseen courses of action created through the interactions between players is precisely what the analyst may be looking for. A good OR analyst always fits the techniques to the problem and not the other way around.

- Simulations take longer to build (because of the complexity of the software), but having built them they are then easily repeatable, run quickly and can be used to explore many variations without the variability in performance of the human players affecting the results. However, simulations risk becoming "black boxes" that are hard to understand because of their sheer complexity.
- A game has the advantage of having real players being able to report back on what they think is happening and to draw insights as to what they could have done differently, or what different resources they would have liked to have had. This insight comes at a cost because the game, although potentially quicker to develop is slower to run, and is always subject to the vagaries of the players.

Ideally analysts will harness multiple techniques in developing an understanding of the problem area, using each in an appropriate manner.

In western nations wargaming is on the upswing as a tool in defence analysis at the time of writing in 2017. Partly this resulted from the U.S. Department of Defense's instructions in 2015 to revitalise work on wargaming in support of increased innovation in defense circles[6]. The Military Operations Research Society has a very active Wargaming Community of Practice and a number of professional gaming conferences have taken place in different nations under the "Connections Wargaming Conference" banner[7].

Structured discussions between real decision makers or between subject matter experts acting as surrogates for the real leaders still fall within the range of techniques recognised by many as part of the OR discipline. Simply adding the structure of Matrix Game arguments to determine the success or failure of player actions, and possibly employing some form of map to display the physical ground truth, can turn simple seminar discussions into a form of game.

Finally, the analyst and the client must be cognisant of the aphorism attributed to the statistician George Box (1979), "All models are wrong but some are useful"[8]. The question is whether the model is illuminating and useful. As the discipline of OR has matured analysts have recognised the value of bringing to bear combinations of approaches when tackling complex problems. Simple and fast-moving exercises involving groups of subject matter experts (SMEs) may explore problems quickly and identify the key issues to study. These key issues can then be investigated using more rigorous mathematical based approaches, the results of which can then be subjected to further SME brainstorming or actual physical tests. The best approach to addressing the most complex problems is a campaigning approach, or cycle of research,[9] in which different types of tools are brought to bear in combination. The whole combined approach is thus more useful, and more credible, than the sum of its parts. This synergistic view is of course not limited to OR, but can also be seen in many engineering disciplines.

The types of model outlined here are quite different and should not be considered to be interchangeable; rather they are complementary. Clearly, we wish to use models that are valid and fit for purpose. Unfortunately, there are different types of validity. A model is said to have

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[6] Deputy Secretary of Defense Bob Work and Gen. Paul Selva,, Revitalizing Wargaming is Necessary to be Prepared for Future Wars, www.warotherocks.com, December 8 2015

[7] See https://connections-wargaming.com/ (USA), http://www.professionalwargaming.co.uk/ (UK), http://www.kriegspiel.com.au/connections.html (Australia) and http://saganetconnections.nl/Engels.html (Netherlands) (all accessed 16 June 2017),

[8] *Box, G. E. P. (1979), "Robustness in the strategy of scientific model building", in Launer, R. L.; Wilkinson, G. N., Robustness in Statistics, Academic Press, pp. 201–236*.

[9] Chapter 9 of Perla, P., (1990) *The Art of Wargaming: A Guide for Professionals and Hobbyists*, Naval Institute Press, ISBN 9780870210501, describes this concept..

internal validity if its working and behaviour are well understood. This is the case for mathematical models. However, the mental models of real decision makers are said to have *external validity* in that they are couched in terms of the real world and not mathematical abstraction. As a general rule models with high external validity have low internal validity and vice versa. Interestingly a Matrix Game can be seen to sit somewhere between these extremes, because anything that could happen in the real world can be argued for, and indeed can happen, in the game. Further, SMEs are able to couch their arguments in real world terms rather than abstract game concepts. The matrix structure breaks down the dynamic flow of events into a cyclical set of arguments and the decision points can be recorded along with the factors determining the probability of success. This leads to the creation of an internally valid model of the conflict as it becomes abstracted as a sequence of changes of state.

Design Issues for Games for Operations Research

This section covers some of the key design issues in a game being used for OR. In each case the unique features of a Matrix Game are considered. Bear in mind that the focus here is the use of games as human-in-the loop models for analysis purposes. The same types of games may be used for training or education purposes, or even as recreational games; in those contexts, the design decisions may be subtly different, but the fundamental issues remain essentially the same.

From this point on we will refer to the game as the complete ecosystem around the game, and not just to the physical components. If a family plays a board game together then for it to be a rewarding experience it is important that everyone understands the rules, that everyone agrees not to cheat and that someone resolves any rules interpretations and tries to keep everyone engaged. The professional game is no different; it just tends to involve more people, more things can go wrong, and the consequences of failure are different. The analyst designing a professional game has to design not only the physical components of the game and all of the rules within it, but everything else that goes around it.

General features of a game

1. **An objective**

A recreational game is played for fun and someone usually wins if the game is played to a conclusion. In an analytical game the objectives are likely to be much more subtle, and the range of possibilities is vast. For example, they could be played to test different strategies for a military operation, to explore how a proposed new piece of equipment could be used on the battlefield, or to develop civil defence plans in case of natural disaster. For the professional analyst the purpose of the game remains a paramount design driver.

2. **A scenario**

Games require a scenario, or in other words a description of what is going on. Scenarios bound the scope of the game and provide participants with a sense of their objectives. For recreational wargamers the scenario describes the battle or war being played. Scenarios may be historical, contemporary, futuristic or completely fictional. Examples might include Caesar's conquest of Gaul (58 BC - 50 BC), the Pacific theatre of the Second World War (1941-1945) or the struggle for power within a fictional contemporary state ruled by a Junta. For professional analysts, the scenarios are more likely to reflect present-day situations, such as the ongoing conflicts in the Middle East or Ukraine, or to be set in the relatively near future. Near future games are important because they help organisations to understand and plan potential responses to possible future crises. Examples include navigating the international economy through a major shock such as the collapse of free trade agreements, the response to a major natural disaster

such as an earthquake, or a military intervention into a region which is not in the news now but which may be showing signs of political instability. The South China Sea represents an area in which several states currently (2017) have conflicting ambitions[10] and which analysts in a number of countries are doubtless exploring.

The scenario provides context for other parts of the game design and may provide constraints under which players must operate. For example, military forces operating under a United Nations peace keeping mandate will behave differently to identical forces engaged in a war of national survival because different rules of engagement will apply.

The scenario is not part of the game design, but is a necessary precursor. The Matrix Game format is very simple and its basic progress through a succession of arguments means that it is possible to play a Matrix Game with nothing but the scenario, although some additional development is usual. Examples include a map and briefing materials for each player explaining their roles and objectives.

3. A control team

Matrix Games involve interaction between people and someone must control those interactions and adjudicate the results of the various actions. Depending on the number of players this task may be performed by one individual or a team including cells behind the scenes adjudicating conflicts or controlling factions that do not have players assigned to them. The role of controller or facilitator is critical for a Matrix Game. Because this type of game requires interaction between players when expressing arguments, and especially when articulating the reasons in for or against them, the management of those interactions is critical. Like any well-run meeting everyone needs to have the opportunity to participate and no one can be allowed to dominate the play through their strength of personality. The Matrix Game also relies upon the adjudication of the strength of arguments and the determination of the outcomes when an argument succeeds or fails. The adjudication and the facilitation can be performed by the same individual, but the division of effort can be beneficial. The adjudicator could also have access to statistical tables, simple calculator-like tools or other aids to assist them in the adjudication. This provides a mechanism to mitigate the lack of underpinning mathematical rigour behind the Matrix Game. By this means the internal validity of the game can be increased at some cost in speed of execution.

4. Player Factions

Part of the game design is to decide the number of "sides" in the game being played by human players. In many conventional defence applications there are two—friendly forces and enemy forces—[11] but there can easily be others if powerful nations, their local allies, international organisations and various factions within the countries being represented in the scenario are played independently. It is also possible to have a game where all players are notionally on the same side albeit with individual objectives.

5. A representation of the physical world

A display of some sort is usually needed to depict where things are spatially. This could be a physical map, possibly with pins in it or counters on it to show where things are. Alternatively, you could use a computer-generated image projected on a screen or some form of online computer display. The map serves a number of purposes. Most importantly it provides a common frame of reference for all players. Players do not have to take notes or remember

[10] See http://www.reuters.com/article/us-usa-china-southchinasea-idUSKBN1572M4, accessed 16 June 2017

[11] Of course, friendly and enemy forces may not be unified forces from a single nation, but coalitions of participants with their own objectives, restrictions and sensitivities.

where thing are; they just need to look at the map (although in some kinds of games players each have a map showing what they are aware of; only the game controllers see the ground truth). Secondly, the map places some additional constraints on player actions. For example, if a player has one construction team available and has assigned them to repair facilities at an airport, then the same engineers cannot repair port infrastructure until they are reassigned and moved. A map might show that all the routes available to an aid convoy between its start point and its destination are controlled by hostile militias. In a Matrix Game this indicates that there will need to be arguments as to why the militias will let the aid pass, or some kind of precursor argument will be needed to counter the militia threat. This added detail and realism can increase the internal validity of the game as a model.

It should be clear that a seminar-like discussion that takes place without being anchored by a map is potentially flawed because it has no spatial frame of reference to constrain the participants.

6. A game-management process

Any game needs a process to manage the flow of the game. This is important to regularise the flow of activity and to ensure internal consistency in the execution of the game. Usually a game-management process needs to allow:

(a) Information to flow to the players to tell them what they are aware of.
(b) Players to decide how they will act.
(c) Players to inform the control team (and possibly other players) what they are going to do.
(d) Control to evaluate Player actions.

The game could flow continuously or proceed turn-by-turn, the former being possible with computer-based games. When using a turn-based approach there are several variations. Players may take their moves simultaneously or sequentially. If the moves are sequential then the order may be fixed, may be random or may be determined by some mechanism within the game. Depending on the type of game the interactions between players and controllers may be through computer networks, written instructions, face to face, or a combination.

In the case of Matrix Games turns are usually sequential and information flows are all face-to-face. This does not stop players or controllers having private discussions or slipping each other hand-written notes. Secret deals and sudden surprises are a part of the real world and can certainly play a part in a Matrix Game. The relatively simple nature of Matrix Games means that game management usually is not a major challenge. As long as players can see and hear what is going on and can inject appropriately to the resolution of arguments, and the game controller can keep the succession of player arguments flowing at a reasonable pace, then the game should succeed, at least mechanically.

7. Action-evaluation mechanism

A game needs a mechanism to evaluate the outcomes of player actions. At its simplest this can be an umpire or adjudicator applying their judgment. The Matrix Game takes this further by using a system based on structured argument for determining how likely an action is to achieve its intended result. More complex types of game may have more comprehensive rules for things like the movement of people or military units between locations, for the gathering of information on hostile forces, for engineering tasks, for the management of logistics and of course for combat interactions. There may also be more abstract game systems like mechanisms for tracking how public opinion changes as a result of player actions. Such rules may be part of a table-top game in which the players or the umpires work through the rules, or they may be built into a computer which executes the moves requested by the players.

As always with game design compromises must be made. A game that is quick to play keeps players engaged and enthusiastic and is amenable to repeated plays. A game that has frequent complicated calculations to perform is either slow to play (if those calculations are done by the players or umpires) or is expensive and time consuming to prepare if it requires software development. However, the more complex games can be considered by some to be more realistic if they are based upon detailed engineering-level models about how things work in the real world[12]. On the other hand as a game becomes more mathematical and detailed in its construction, what it may gain in internal validity comes at a price of declining external validity. In a complicated rules-based game a player can only do something for which there are established rules. Game controllers may be reluctant to introduce new rules "on the fly" especially if the game is part of a series that needs to be consistent. Any innovative idea that is not already covered by the rules is simply not permitted. For example, a player might want his forces at the border to dig defensive positions to impede an enemy attack. If there are no rules for fortifications of this type then the player simply cannot do it, or it will have no effect. Game credibility will suffer if players start to feel that the game is incomplete as gaps appear or umpires are noticeably improvising. In a Matrix Game the player simply argues why he can do it and what effect it will have and the argument-resolution process determines whether or not it succeeds.

As a result of all its characteristics Matrix Games develop a narrative through the succession of arguments made. Because arguments build upon the precedents set by others the Matrix Game becomes a single narrative thread drawn through the infinite number of possible narrative threads that describe how the situation defined in the scenario could unfold. Other sorts of game can also be used to create a narrative, but the Matrix Game has a unique strength of not limiting the players to work only with the things for which rules exist, while at the same time having a turn structure and (usually) a map to provide a more systematic and grounded process than an unstructured seminar discussion.

Summary

A game needs a context (typically defined in its scenario), players to make leadership decisions, mechanisms to evaluate the player decisions, a map of some sort to indicate where things are, and a control team and a game management process to make the game work. There are a huge number of possible ways of doing this. The next section will look at some of the specific choices that need to be made in designing a Matrix Game to facilitate operations research studies.

Design Issues for Analytical Matrix Games

Game Purpose

It is very important to be crystal clear from the outset what the purpose of the game is. In the recreational gaming space this is usually quite obvious. In that context the purpose is to allow the players to compete with each other using a model of a real or imaginary conflict and to allow someone to be declared the winner[13]. There are further design issues concerning realism, playability, scope and physical limits of the playing environment, but the purpose is not in doubt.

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[12] The level of detail in a game design is a critical part of the art of game design. Decisions must be taken as to what to represent and at what level of fidelity. A game with very detailed calculations on weapon performance but no consideration of the training level of the soldiers using those weapons may look impressive but is likely flawed in comparison to games with a simpler treatment of a broader range of factors.

[13] It is also possible to have games where cooperation is required and all players may win or all lose, or any combination.

With analytical games the identification of the purpose is subtler. Games may be developed for any number of reasons. Some examples include:

- To familiarise players with the nuances of a scenario, or to give them insight into its intricacies.
- To elicit SME input to capture likely narrative threads in a scenario.
- To test the internal consistency and rationale of a scenario.
- To assess the utility of one or more types of military (or civilian) capability in a scenario.
- To explore possible outcomes of a scenario.
- To evaluate and improve existing plans for responding to a real-world scenario.
- To get the stakeholders in an analysis engaged in the process and feel that they are taking part.
- To allow leaders to rehearse a mission or their response to a crisis, without having to put real people and equipment in the field (which is very expensive).
- To facilitate the formation of teams who may have to collaborate in future crises or planning activities.

A Matrix Game is an option for some, but not necessarily all of these applications. In particular, it is risky to try to draw any form of quantitative results from a Matrix Game. Questions about numbers, distances or time usually cannot be addressed and even assessing the likelihood of reaching certain end states is questionable because each play of a game is just one of an infinite number of possible narratives.

Where Matrix Games are most powerful is in exploring the behaviour of complex systems. By definition complex systems are those whose behaviour cannot be perfectly predicted[14]. Examples of complex systems include a failed state or a political election cycle. There are too many variables and too many possible events to be able to predict definitively what will happen. Because models with higher degrees of internal validity cannot easily be created of true complex systems the Matrix Game provides a structured mechanism for human players to bring their individual perspectives, insights or even specific expert knowledge to bear. In time, exploration of a complex scenario using a Matrix Game might allow a more tightly defined and revised appreciation of the situation to emerge. This in turn may allow different sorts of gaming or modelling techniques to be applied to a narrower problem.

No game is going to provide robust predictions. The variability of player choices and their behaviour is always going to make the outcomes of games difficult to use as direct predictors of outcomes of real-world events. The principal value of a game will always be the insights and learning players derive from each other and from playing the game itself[15].

Design Features of a Matrix Game as an OR tool

Scope and Purpose

The designer of an analytical Matrix Game needs to ensure that the game is designed to explore the issues identified by the game sponsor and does not risk the narrative thread's heading off

[14] Rocha, Luis M. [1999]. *BITS: Computer and Communications News*. Computing, Information, and Communications Division. Los Alamos National Laboratory. November 1999.
[15] Perla, P., (1990) *The Art of Wargaming: A Guide for Professionals and Hobbyists*, Naval Institute Press, ISBN 9780870210501

into areas that are not pertinent to the study of which the game forms a part. Players can be directly told the purpose; for example, to identify issues regarding collaboration between governments, aid agencies and military forces responding to a natural disaster. Alternatively, players can be gently nudged in the right direction, in this case by showing them a map with lots of markers representing groups of internally displaced people, outbreaks of disease or damaged infrastructure. The players should naturally be drawn to the humanitarian challenges before them and seek to resolve, manage or exploit them. Players representing military commanders shown the same map but with markers representing arms caches, hostages and rebel groups are likely to launch counterinsurgency operations rather than humanitarian ones. Of course, if the objective of the game was to explore events that could occur if a certain state failed in the future then the players should be given as little guidance as possible. In this case players representing internal factions within the state, or external powers or organisations, should be given free rein to be creative.

Evaluation Mechanisms

The making and resolution of arguments is the fundamental part of the Matrix Game that differentiates it from other forms of game. In most professional games the umpire determines the outcome of actions after weighing the arguments and applying their own judgment, or players may come to a consensus. In most recreational games, and in many professional games, a chance factor is introduced. Many resolution mechanisms involve determining the likelihood of success of an argument and then rolling dice to determine success or failure. Reasons for or against the argument can be used either to modify the score needed to succeed (e.g. "You have two good reasons in favour and there are none against, so you need to score at least 5 on two dice.") or as a modifier to the dice roll (e.g. "You have two good reasons in favour and there are none against, so you have a bonus of +2 on your roll. As always the argument succeeds on a 7 or better.")

The game designer must decide in advance how arguments will be formulated and how they will be resolved. Some earlier formats of Matrix Games used cards with key words on them and players had to build their reasons using words on cards in their hand. That approach has been largely supplanted by more free-form games in which players are not limited in the ideas that they can use. This is another example of how game design has to support the purpose of the game. If games are being run to determine priorities for investment in the armed forces then players could use decks of cards with the names of types of equipment (e.g. tanks, fighter aircraft, drones) or other concepts (e.g. superior training, tactics, intelligence). Analysts would pay very close attention to the choices of cards and the combinations of them as military commanders formulated their arguments as to why their actions would succeed. For example, why invest in tanks if no commander in a game cites having one as a reason why they would succeed in achieving their objectives?

Another design decision for a Matrix Game is the number of underlying rules. At one end of the spectrum the designer could have a complete, conventional rules-based wargame. The matrix arguments are then used to bring in exceptional elements not covered by the rules or to modify the rules. For example, through arguments like:

"My units will have a large bonus in fighting the enemy blocking the pass because:

(1) They are elite forces;
(2) they will attack at dawn with the sun at their backs so the enemy forces are blinded; and
(3) my best general will personally lead the attack."

If this argument succeeds then the combat will be resolved using the existing game rules but with some bonus determined by the umpire applied to the attack. In this case factors such as

heroic generals leading an attack or the benefits of an attack against an enemy blinded by a low sun can be included in a game that has no rules for those factors. At the other end of the spectrum the designer could have no underpinning rules and will resolve everything through matrix arguments. An example of this would be:

"My units will successfully land on the beach and defeat the enemy defenders because:

(1) They have the advantage of surprise;
(2) they have rehearsed the attack;
(3) they have supporting airpower; and
(4) they have special armoured vehicles to get them through any obstacles"

In this case if the argument succeeds then the attack will have succeeded and no underlying rules for resolving a battle are needed. In either case if the argument succeeds then a precedent has been set that attacks carried out in this manner are indeed more effective and this precedent can be referred to in the resolution of future arguments. This could be in a positive sense, such as when the same unit makes another attack, or in a negative sense as a factor running against a subsequent enemy counter attack to retake the position. However, the umpire will need to be careful and use discretion with this kind of precedent being set by arguments. If the presence of supporting tanks were used as a reason in favour of an argument about an attack, but the argument were to fail, it might still be unreasonable for the presence of tanks to henceforth be cited as a reason why future attacks would also fail.

A more rules-based Matrix Game may be appropriate where there are key activities for which some more internally valid model exists—such as tables of probabilities of suspects being arrested, or models of combat between fighter aircraft. The more free-form game is likely to be more appropriate where arguments are going to take place in the strategic or political domains where there are less well-established metrics. A mixed approach is also possible with some factors being derived from other kinds of analysis and being plugged in where appropriate. Perhaps analysis of real combat might show that attacking with a two-to-one advantage in manpower should be given a +1 factor on the die roll when resolving a battle through a matrix argument, while having air strikes in support should be a +2 factor. In effect this means that the umpire has access to a list of pre-assessed reasons that reduces his/her workload during the game and improves consistency.

Whatever mechanism is used to resolve actions in the game it is paramount that the resolution be consistent, both within one game and across a series of games being run as part of some analytical exercise. For example, if the umpire rules that "because it is snowing" is a weak reason in arguments about whether agitators can start a riot then it must always be a weak reason in similar contexts in this and subsequent games. To aid consistency, and for subsequent post-game analysis, it is best practice to record player arguments and umpire decisions about their merits.

Selection of players

It is generally accepted that the best way to be sure of analysing a complex problem thoroughly is to make sure that we take multiple looks at it from different perspectives using multiple methods, analysts and data sources. If we decided to use a Matrix Game as a tool to explore a scenario we may also need to play it multiple times with multiple combinations of players. This is the scientific version of seeing wisdom in second opinion. Because a Matrix Game can be played quickly it may be feasible to play it several times with different players and even to have different analysts observe the games and record their observations.

The idea of using multiple players to undertake multiple replications of the game raises some new questions that are important in the design of the games. Namely, who do we want to play it and how do we ensure that the games are played consistently? Players can be drawn from three broad groups:

- Firstly, players can play in their real professional roles, be that senior military officer, newspaper editor or head of state. Clearly this approach can be difficult for some scenarios, but it is sometimes feasible to get the board of an organisation to play some form of game exploring business strategy.
- Secondly, one can employ SMEs as surrogates for senior leaders. When looking at a hypothetical future scenario this is often the best option available. Examples might include junior military officers playing the role of more senior commanders, or commanders from a different nation, or political scientists playing the role of the governments they have studied. Experts in their subject bring a rich understanding about what courses of action are feasible and may well be able to improve the quality of the game by making well informed injects into the resolution of arguments. However, experts may also follow preconceived lines of thinking (group-think) and try to provide what they perceive as a correct input rather than being creative.
- The third group represents everyone else who may be a player; they may be employees from the analyst's or the client's organisation tasked to participate or self-selecting volunteers. They may have some general knowledge of the subject of the game and the participants but won't bring informed insights into the game's execution. Analysts may have no choice but to use whomever they can when the first two classes of player are not available. This third group can be valuable because they may introduce lateral thinking into the game. The umpire must always distinguish between valid lateral thinking, and ideas that are just not practical because of real world constraints such as logistics

No matter the source of the players there will be things that they need to know about the scenario. The players of a well-planned game should receive packages of information to immerse themselves into the scenario and their role. This may run from a few paragraphs to many pages. The design team must balance immersing the payers in extensive rich contextual information, which they may not read, and giving them something short and to the point, which they will actually take on board. A game set in the present day around a familiar subject and using expert players will require less preparatory material than a game using volunteer players to explore a hypothetical scenario set some years into the future. Effort invested in preparing players is rarely wasted. In this sense a professional Matrix Game is more akin to a role-playing game than a conventional recreational wargame.

Umpire Interventions

It is possible for umpires to inject their own reasons into player arguments or even to add their own arguments. Such approaches should be used cautiously and only where the game's purpose merits such intervention. For example, if the purpose of the game is to allow the players to explore and better understand a real or hypothetical crisis then it would be entirely appropriate to enrich the experience with additional contributions from the umpire. If on the other hand the game is one of a series collecting data on the courses of action chosen by players in response to a crisis then a new twist added by the umpire could invalidate the game. The key is for the umpire by keep the games within the bounds set by the game sponsor, but still allow players freedom to explore.

Player motivation and engagement

At the end of the day the game designer and the umpire controlling the game should seek to make the experience a positive one for the players. This is true in professional analytical games just as in recreational games, although the attention spans and boredom thresholds may be different. The game needs to move at a reasonable pace without players feeling that they have been forced into hurried actions. At the same time the purpose for serious games is to learn things and the discussions that break out on the subject of the game may include valuable insights or ideas. Such discussions should not be cut off too quickly, but in the interests of completing the game the umpire may request that the player(s) concerned write down their points later.

The umpire should not entertain discussions about the game itself, unless the game dynamics have started an insightful conversation that is invaluable. If the game has been properly designed and tested before being played for real then there should not be any major flaws. Players should be briefed on the game and its rules before commencing. Ideally, they should play a practice game or at least a round or two, so that they are comfortable with the key mechanisms for expressing and resolving arguments before the game starts in earnest. If a player still has reservations about the game's design or execution after adequate preparation then the umpire should seek to avoid a lengthy debate of the issue, but politely insist on continuing the play of the game. That said the perfect game has yet to be designed and so umpires and designers should encourage constructive criticism and feedback on the game at the end.

Conclusions

The scientific method is founded on the basis of advancing hypotheses and then collecting data through experiments to support or refute them in a transparent manner so that others can follow the process. The Matrix Game presents players with a complex system—the situation described in the scenario—and invites them to advance hypotheses about it. Rather than conducting experiments in the field or in a laboratory to validate the hypothesis, the Matrix Game allows the players and umpires to evaluate the likelihood that the hypothesis is true based upon their expertise, experiences and intuition and then a roll of the dice decides whether, for the purposes of this game, the hypothesis is true. In effect the participants conduct a mini judgment-based operations research study on each hypothesis in turn. What is more, the resolution of one hypothesis may provide a precedent upon which further hypotheses can be built. For example, in a Matrix Game based on the War of 1812 if the British have successfully argued that the Americans are terrified of Native American warriors then they can subsequently cite that fear as a reason against subsequent American arguments to successfully recruit fresh soldiers to replace their losses.

The engagement of SMEs who are not constrained by an abstract game design as to what issues they introduce into arguments gives the Matrix Game high external validity; that is, people can see how it is related to the real world and can follow the narrative as it unfolds. At the same time breaking the game down into a succession of mini thought experiments to test hypotheses adds far more structure than a seminar-style discussion or brainstorming session.

The Operations Research analyst may thus find Matrix Games to be a valuable addition to their toolset to explore certain types of complex human-centric systems for which underlying mathematical models are missing.

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