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Game-Theoretic System Design in the Development of Space Power

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Introduction

The US space enterprise plays an integral role in maintaining the peace and prosperity of the nation. In times of conflict, the country depends on American space power. Leaders within the US space community advance space power through the evaluation and execution of strategically interdependent decisions. These decisions pertain to the technology development, acquisition, and operation of space systems and are analogous to moves, strategies, and payoffs in multiplayer games. Using game-theoretic models, decision-makers possess the valuable opportunity to partially manipulate game structure before stepping into the role of a player. To bolster this hypothesis, this article presents several game-theoretic system design concepts. First, this article contextualizes the spectrum of agent strategic interactions, from collaboration through competitive to more antagonistic outcomes. Second, a new taxonomy for the classification of game-theoretic models is proposed. Third, we expound on the proposed taxonomy using eight atomic game structures and exemplify their use with pertinent space applications.

Game Theory

Game theory dates back to work by John Von Neumann in 1928. With wide applications in political science, economics, biology and genetics, sociology, linguistics, and even system design, game theory is a tool to solve decision-making problems. A game involves a set number of players, strategies (decisions, possible moves, or actions), and a payoff or value that captures the outcome of each play per player.[1] The strategy or strategies for each player can be simple and small, or complicated. Consider chess, where the number of possible moves and strategies are massive. But even for atomic games with two players and two possible moves each, one can observe interesting and counterintuitive scenarios and equilibria. Three important aspects of game theory include agent utility balance, Nash equilibrium, and the Pareto front.

Agent utility balance states that an outcome holds approximately the same utility for all agents.

Nash equilibrium relies on the conventional use of the term in the field of game theory—a set of strategies, one for each player, such that no player has an incentive to unilaterally change their current decision or move.[2] A player achieves a pure-strategy Nash equilibrium (where such equilibrium exists) by playing a single strategy. A player can achieve indifference in the other player(s) through a mixed-strategy Nash equilibrium wherein a set of pure strategies are played with some probability.[3]

Generally, **Pareto optimality** exists when no single criterion can be improved without diminishing at least one other criterion. In the case of a two-player game, the two-dimensional Pareto front considers each agent utility as a positive asset for maximization. The Pareto front is formed using nondominated outcomes within the game-theoretic model.[4]

The Atomic Competitive Element Taxonomy

The Atomic Competitive Element (ACE) taxonomy presents an abstract and descriptive decision space that illustrates contextually desirable attributes. Therefore, an understanding of the ACE taxonomy encompasses comprehension of that context, specifically, agent goals and the resultant behavior. While the user may frame any game-theoretic model with the ACE taxonomy, situations containing self-interested players (who nonetheless display a willingness to cooperate to achieve a mutually beneficial outcome) provide the most natural fit. Close allies with a shared goal, working toward a collaborative outcome, often diverge from the ACE taxonomy construct. Similarly, hostiles committed to self-deleterious min-max strategies frequently eschew such a framework. The span between these extremes—including self-interested cooperators, competitors, and belligerents—fit naturally into the ACE taxonomy construct.

Collaborative outcomes maximize the collective utility of the agents within the game. Close allies with a shared vision, generally common values, and a shared goal, often work toward such outcomes; each agent sees the team success as personal success. Under certain circumstances, such an approach can maximize both coalition and individual utility over the long term. By maximizing team utility, collaborative outcomes always exist on the Pareto front. Collaborative outcomes do not fit as naturally within the ACE taxonomy framework.

Cooperative, competitive, and antagonistic outcomes always use Nash equilibria as the baseline solution. Agents working toward a cooperative outcome are willing to move from a Nash equilibrium to a mutually beneficial outcome with a higher utility for both players. In a cooperative context, agents treat each other benevolently and work for the betterment of other agents as long as the respective individual agent garners a positive or neutral result. Cooperative outcomes generally fall on a Nash equilibrium or a Pareto front outcome with adequate utility balance and mutual utility improvement. They also generally maximize individual utility within a specific game. Allies with shared interests work together toward the same outcome. Importantly, agents within such a context need not demonstrate altruism (i.e., agents act in self-interest), but the agents must trust each other and act in good faith.

Naturally, competitors pursue competitive outcomes and seek to maximize individual utility through individual effort. Competitive outcomes land on Nash equilibria. Agents within such a context display indifference toward other agents—seeking neither good nor harm for fellow players.

Antagonistic outcomes display the same characteristics as competitive outcomes except that, in such a context, agents choose to harm each other when there is no cost to do so. For example, an agent given two options with the same personal utility would follow a min-max strategy to minimize the other agent's utility. Cooperative, competitive, and antagonistic outcomes, as well as the associated agent behavior, naturally fit into the ACE taxonomy framework.

In a hostile context, adversarial players engage in a pure min-max strategy wherein every choice minimizes the other agent's maximum possible utility.[5] When seeking a hostile outcome, agents pursue this min-max approach even when such a strategy presents self-detrimental consequences. Interestingly, these hostile agents are not self-interested and can be trusted to always commit the most harmful action. Hostile outcomes and belligerents do not fit into the ACE taxonomy construct. Reference figure 1 for the spectrum of interaction among agents in a game.

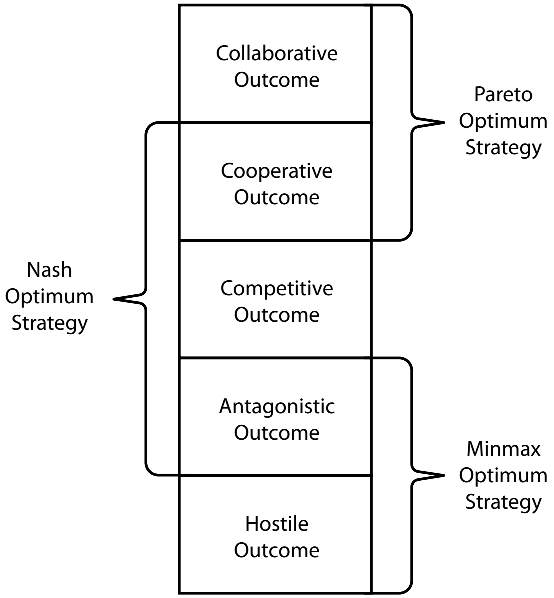

Figure 1. Spectrum of interaction

The ACE taxonomy illustrates and classifies game-theoretic models according to three contextually desirable attributes (for the stability of an outcome), which may exist in a particular outcome: agent utility balance, Nash equilibrium, and the Pareto front.

The ACE taxonomy represents these three attributes with primary colors, their combinations with secondary colors, the presence of all three attributes with white, and the absence of all three attributes with gray. Reference figure 2 for the Venn diagram illustrating the ACE taxonomy.

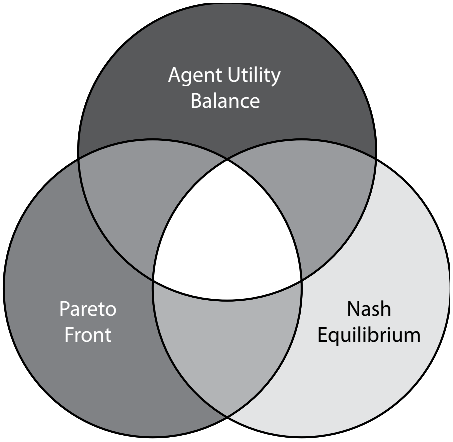

Figure 2. Factors of stability in multiagent games

Characterization of Atomic Competitive Elements

This section introduces and characterizes eight fundamental building blocks of ACE that are significant in the formation of many higher-complexity game-theoretic models. The user of this taxonomy may recognize each kind of ACE by its unique color scheme based on the three properties (agent utility balance, Nash equilibrium, and the Pareto front) present or not within each of the four outcome cells of the respective two-by-two matrix. This taxonomy does not consider game-theoretic models as unique ACE wherein the game designer may trivially rearrange the choices of the respective game to achieve a repeated color scheme. Systematically categorizing game-theoretic models at a fundamental level empowers the user to identify the scenario at hand, understand the scenario's dynamics, and draw upon heuristic solutions to maximize the utility for one or more agents within the game. Specifically, this article uses this taxonomy to address challenges and opportunities in the development of space power.

Deadlock

In Deadlock, each player knows both the correct and incorrect answer and must simply choose the correct answer. If both players choose the same answer, they earn a neutral utility value. If one player makes an unforced error, the winning player achieves positive utility at the expense of the losing player. Importantly, this game, as well as the other games, are presented in a strategic form where both players must act simultaneously; players do not know what the other player will do, and prior communication or coordination is not guaranteed.

Perhaps the most stable and simple game-theoretic model, Deadlock contains a single balanced pure-strategy Nash equilibrium on the Pareto front. Deadlock presents a straightforward, intuitive scenario wherein agents converge to the Nash equilibrium with no opportunity to improve utility through cooperation.[6] Other outcomes within Deadlock represent unforced errors by one or more agents. Reference table 1 for the game of Deadlock using the ACE taxonomy.

Table 1. Deadlock

	Deadlock	Player Two	
		Error	Correct
Player One	Error	0,0	-1,1
	Correct	1, -1	0,0

Pure Coordination

In Pure Coordination, players must decide to stay or go. If both players choose the same answer, both players achieve a positive utility. If players differ in their choices, neither benefits.

The self-explanatory Pure Coordination game-theoretic model presents an extremely stable game in the presence of effective communication with two balanced pure-strategy Nash equilibria on the Pareto front and one mixed-strategy Nash equilibrium.[7] Since the payoffs for both pure strategies hold the same utility for each agent, players of the game display indifference in the pursuit of a particular pure strategy and act amiably in the respective coordination. Reference table 2 for the game of Pure Coordination, using the ACE taxonomy.

Table 2. Pure Coordination

	Pure Coordination	**Player Two**	
		Stay	**Go**
Player One	**Stay**	**1, 1**	**0, 0**
	Go	**0, 0**	**1, 1**

Stag Hunt

In Stag Hunt, each player must decide to hunt the stag or hunt the two hares. Hares can be caught by one player, but the stag requires both players working together to catch it. If each player hunts for hares, each will catch one hare and achieve a utility of one. If both players hunt for the stag, each will achieve a utility of three, since the stag is worth six total utility. However, if one player hunts for hares, that player will catch both hares and achieve a utility of two, while the other player will earn nothing since they will be unable to singlehandedly catch the stag.

Stag Hunt generally represents the synergistic effect of cooperative resource harvesting with one pure-strategy Nash equilibrium on the three-cell Pareto front, one pure-strategy Nash equilibrium off the Pareto front, and one mixed-strategy Nash equilibrium.[8] The Pareto front pure strategy presents high stability in the presence of effective communication and the absence of adversarial intentions. In a similar fashion to other ACE, such as Stoplight and Chicken, this game presents the opportunity for game-theoretic system design to expand the scope of the scenario to achieve a higher utility for both players. The game designer may translate the strategic form of the game to an extensive form and introduce a new branch on the first node with outcome utility less than the utility of synergistic harvesting but greater than individualistic harvesting. Given logical, sophisticated agents capable of forward induction, the players will not use the new branch and will instead converge to synergistic resource harvesting.[9] Reference table 3 for the game of Stag Hunt using the ACE taxonomy.

Table 3. Stag Hunt

	Stag Hunt	Player Two	
		Stag	Hare
Player One	Stag	3, 3	0, 2
	Hare	2, 0	1, 1

Matching Pennies

In Matching Pennies, each player decides whether to play their coin heads-up or tails-up. One player wins if both coins match while the other player wins if the coins do not match.

Matching Pennies represents arguably the most unstable simple game-theoretic model with no balance, one mixed-strategy Nash equilibrium and a four-cell Pareto front that spans the entire decision space. In Matching Pennies, one agent attempts to match the metaphorical penny while the other agent works to prevent the match.[10] Reference table 4 for the game of Matching Pennies using the ACE taxonomy.

Table 4. Matching Pennies

	Matching Pennies	Player Two	
		Heads	Tails
Player One	Heads	1, -1	-1, 1
	Tails	-1, 1	1, -1

Stoplight

In Stoplight, two drivers arrive at an intersection simultaneously and must decide whether to continue or stop. If one continues, that driver will gain a utility of one while the other driver will be indifferent. If both players stop, both players will be mildly annoyed and lose one utility value. If both players continue, they will cause an accident greatly detrimental to their utility values.

Stoplight represents the quintessential game-theoretic model for the application of correlated equilibrium with two unbalanced pure-strategy Nash equilibria on the Pareto front, one mixed-strategy Nash equilibrium, and two balanced, mutually deleterious outcomes off the Pareto front.[11] In the Stoplight model, logical agents use a correlated equilibrium mechanism (perceived as fair by all agents) whenever possible to maximize overall and individual utility. Reference table 5 for the game of Stoplight using the ACE taxonomy.

Table 5. Stoplight

	Stoplight	**Player Two**	
		Continue	**Stop**
Player One	**Continue**	**-5, -5**	**1, 0**
	Stop	**0, 1**	**-1, -1**

Fundamentally, Stoplight represents the same ACE as both the Battle of the Sexes and Volunteer's Dilemma game-theoretic models. Stoplight addresses safe traffic flow, Battle of the Sexes addresses coordination (or lack thereof) for an entertainment venue, and the Volunteer's Dilemma addresses costly intervention to help a crime victim.[12] Effectively, since each of these game-theoretic models represents the same kind of ACE, game agents, or the game designer may use a fair correlated equilibrium mechanism to achieve a higher utility.

Prisoner's Dilemma

In the Prisoner's Dilemma, an interrogator can convict two players of minor crimes without a confession such that each player will spend one month in jail. The interrogator offers a plea bargain to both suspects where they can sell out the other player for personal leniency—if only one player takes the deal, that player will receive no time in jail while the other player will spend 12 months in jail having been successfully convicted of the more serious crime with the help of the defector's confession. However, if both players confess, their confessions are worthless, and each will receive eight months in jail on the charges of the more serious crime.

The Prisoner's Dilemma represents arguably the most famous game-theoretic model with a single pure-strategy Nash equilibrium off the Pareto front. The game demonstrates the difficulty among self-interested, untrustworthy agents in moving from the Nash equilibrium to a balanced, mutually beneficial outcome. The difficulty in establishing the mutually beneficial outcome lies in the opportunity for profitable deviation by an untrustworthy agent.[13] Reference table 6 for the game of Prisoner's Dilemma using the ACE taxonomy.

Table 6. Prisoner's Dilemma

	Prisoner's Dilemma	Player Two	
		Silence	Defect
Player One	Silence	-1, -1	-12, 0
	Defect	0, -12	-8, -8

The Prisoner's Dilemma forms an important conduit to understanding other game-theoretic models such as the Optional Prisoner's Dilemma, repeated Prisoner's Dilemma games, the Tragedy of the Commons, the Hawk-Dove game, and duopolistic competition.

The Optional Prisoner's Dilemma represents an exogenous manipulation of the traditional game and enables an agent to abstain when playing with a perceived defector to achieve a higher utility. Repeated Prisoner Dilemma games allow for higher levels of cooperation and more sophisticated strategies such as tit for tat; an unknown or infinite number of Prisoner Dilemma games aids the strategic enhancement for improved utility. Scenarios that permit proactive self-determined agent mixing (players may choose which agent to play with from the available pool) especially increase the utility value for cooperative agents. Robert Axelrod explored the concept of the Prisoner's Dilemma in his developing notion of cooperation as an evolutionarily stable strategy.[14] In his work with the Prisoner's Dilemma, Ahmed Ibrahim contended that "evolutionary mechanisms have nothing to do with conflict between the causes of the tragedy and their solutions for it, whether the solution is that of outcompeting the tragedy or its contrary." In considering the existence of cooperation among organisms, Ibrahim asserted the presence of a conscious intervener.[15]

The Tragedy of the Commons represents a more unwieldy N-player version of the Prisoner's Dilemma where at least one agent exploits a common resource for personal gain to the detriment of the common resource and the community. Garrett Hardin suggested privatization and top-down regulation (mutual coercion) as remedies, implicitly assuming the existence of a strong, efficient central authority.[16] Elinor Ostrom focused on bottom-up institutions and articulated conditions that fostered such cooperation: easy-to-monitor resources, moderate rates of change, robust social networks, the ability to exclude outsiders, and a strong push for self-enforcement among community members.[17] The pseudonymous Satoshi Nakamoto utilized cryptography to protect a common in the form of a public ledger.[18]

The Hawk-Dove game exists as a superset of three simpler games wherein the Prisoner's Dilemma fundamentally represents the manifestation of relatively low-cost conflict. The game designer, by exogenous manipulation, may significantly increase the relative cost of conflict with respect to the value of the prize to transform the Prisoner's Dilemma into a game of Chicken. Such a transformation creates a new set of strategies as well as new pathways for game-theoretic system design.

The dynamics of the Prisoner's Dilemma, to some degree, check the spread of collusion in duopolistic competition and preserve the health of a limited marketplace.

Take or Share

In Take or Share, each player must decide whether to take the pot of money or share the pot of money worth eight dollars. If both players share, they will split the pot. If both players take, each will receive no money. If one player takes, that player will receive all the money while the other player receives nothing.

In the Hawk-Dove superset, Take or Share represents the knife-edge transition from Prisoner's Dilemma to Chicken as the relative cost of conflict increases. Outside of artificial or discretized environments, such knife-edge equilibria do not exist. Take or Share encompasses three pure-strategy Nash equilibria and infinitely many partially mixed strategy Nash equilibria.[19] Reference table 7 for the game of Take or Share using the ACE taxonomy.

Table 7. Take or Share

	Take or Share	Player Two	
		Share	Take
Player One	Share	4, 4	0, 8
	Take	8, 0	0, 0

Chicken

In Chicken, two drivers drive toward each other at high speeds in a show of bravado. If both drivers swerve, nothing will happen. If both continue, each will be engulfed in a devastating accident. If one swerves, that player will be embarrassed for having lost the intimidation game, while the player who continued will gain positive utility in the form of a fearless reputation. Incidentally, the authors recommend against playing the game of Chicken.

Chicken represents arguably the most fascinating simple game-theoretic model with two unbalanced pure-strategy Nash equilibria along a three-cell Pareto front as well as one mixed-strategy Nash equilibrium. Generally, Chicken exists as an intimidation game with high-value assets at stake and represents relatively high-cost conflict in the Hawk-Dove superset. The mixed-strategy Nash equilibrium enables the use of comparative statics that demonstrate a dramatic decrease in the probability of conflict for any incremental, mutual increase in the cost of conflict. Political scientists use such results to explain the role nuclear weapons play in peacekeeping under the construct of mutually assured destruction.[20] Reference table 8 for the game of Chicken using the ACE taxonomy.

Table 8. Chicken

	Chicken	Player Two	
		Continue	**Swerve**
Player One	**Continue**	**-10, -10**	**2, -2**
	Swerve	**-2, 2**	**0, 0**

Counterintuitively, increasing the cost of conflict improves the overall payoff for an agent within the Chicken game when playing the mixed strategy. However, throwing the cost of conflict disproportionately out of balance significantly increases the chance the agents play the pure-strategy Nash equilibrium deleterious to the respective agent.

Exogenous control accounts for the cost of conflict in the game of Chicken (high-cost Hawk-Dove) where each agent makes a binary choice between conflict and peace. In a game where agents may choose a private commitment of resources to some conflict (i.e., a cost known only to the respective agent), Maynard Smith discovered the evolutionarily stable strategy of generating an exponential distribution using the value of the prize of the conflict as the beta parameter and randomly drawing from that distribution to determine the acceptable value of the cost of the commitment to conflict. Given that the expected value of the cost of the conflict equals the value of the prize of the conflict, the expected overall utility for such a stable approach equals zero. Therefore, Smith suggested the use of some credible mechanism for correlated equilibrium to improve the utility for both agents; he later learned certain animals use the ownership principle as that mechanism.[21]

Space Power Applications

Space Debris and the Prisoner's Dilemma

The development of space power offers each nation the opportunity to bolster its technical acumen, national prestige, and instruments of war. Among the many facets of space power, direct ascent antisatellite (DA-ASAT) weapons offer an instructive case study on the generation of space debris. Perhaps the four most pertinent events related to DA-ASAT weapons and space debris include the 1985 destruction of the US P78-1 Solwind satellite, using an air-launched ASM-135 (during the era of the Strategic Defense Initiative), the 2007 destruction of the Chinese FY-1C (Fengyun, "Wind and Cloud") satellite using a ground-launched SC-19, the 2008 destruction of the US USA-193 satellite using a sea-launched Standard Missile-3 (Operation Burnt Frost), and the 2019 destruction of the Indian Microsat-R satellite using a ground-launched Prithvi Defense Vehicle Mark-II (Mission Shakti, "Power").[22] All four of these satellites experienced destruction at the hands of their owners, and each event caused significant orbital debris. Notably, however, the US and India conducted their tests in such a manner as to deorbit all the debris within several years and much of the debris within the first several weeks and months. In contrast, China's demonstration contributed to the formation of a perpetual low-earth orbit Kessler field.

Beyond DA-ASAT weapons, many other space activities and events contributed to the debris cloud in space. Spacefaring nations often leave spent rocket bodies and nonfunctional spacecraft in orbit, finding such an approach more economical than returning the artificial satellites to Earth. Many of these objects undergo physical explosions (e.g., explosions caused by the pressure buildup in the fuel lines) or chemical explosions (e.g., a hypergolic ignition of residual propellants, an explosion caused by severely decayed batteries, or the purposeful self-destruction of Soviet Union satellites) that further contribute to space debris pollution. Satellites often face the threat of conjunction (i.e., accidental, hypervelocity, destructive collision); the 2009 Cosmos 2251 and Iridium 33 collision provides the most destructive, polluting example. The Soviet Union contributed to the space debris field with spacecraft that leaked sodium-potassium droplets (meant to cool the nuclear reactor onboard the respective satellite) into orbit.[23]

In each of the aforementioned scenarios, the agents involved chose an action to maximize individual utility to the detriment (directly or indirectly) of the space community as a whole. During the era of the US and Soviet Union bipolar dichotomization of power, such events functioned within the context of a Prisoner's Dilemma. With a larger and growing community of modern spacefaring entities (to include the US, Russia, China, the European Space Agency, Japan, India, South Korea, North Korea, Iran, and Israel), the current space debris events occur in the framework of a Tragedy of the Commons.[24] While nations utilize the more egregious events as political weapons within the international community, no mechanism exists to definitively prevent the creation of space debris. The 1967 Outer Space Treaty prohibits the privatization of space, and no top-down organization currently wields the power necessary to impose and enforce space debris regulations on the collective group of spacefaring nations.[25] The factors that would contribute to the effective formation of bottom-up institutions capable of addressing the space debris issue simply do not exist. The innovation of technologies capable of addressing the space debris problem (e.g., reusable rocket bodies, mechanical space debris collection devices, or lasers used to deorbit space debris) afford a worthwhile goal. The political efforts to prevent the proliferation of harmful space debris also provide an avenue for potential progress. However, the core characteristics of the Prisoner's Dilemma ACE and the associated game-theoretic models suggest the inevitability of an increasingly polluted space. Therefore, the main thrust of the US efforts in this field should be in the development of spacecraft capable of surviving and operating in such an environment—not in the attempt to prevent the formation of such an environment. Increasing the resiliency of spacecraft to hypervelocity impacts, using simpler, cost-effective replaceable spacecraft, disaggregating satellite constellation architectures, or transitioning to less-polluted orbital regimes all provide potential avenues for such an undertaking. In a polluted yet still usable space environment, spacecraft maneuver also provides a mechanism for survivability. However, the finite fuel onboard a satellite mandates the prudent use of any such maneuver. To ensure spacecraft maneuvers are conducted judiciously and effectively, the US requires a robust array of space domain awareness capabilities, including both ground-based and space-based sensors and processors.

Department of Defense Policy and Deadlock

Deadlock illustrates the self-imposed damage of unforced errors by one or more agents. A plethora of policies, some worthy of several research papers, guide the personnel and technological development of the Department of Defense, including the US Space Force. Any of these policies that inadvertently cause a substantive number of talented people to exit the US military might be considered an unforced error. Furthermore, policies that neglect the development of critical technologies (e.g., cyber) might be considered unforced errors. When agents do not understand the implications of their actions or hold some other goal as a higher priority, they may fail to reach the stable equilibrium within the Deadlock ACE.

Conjunction, Collision, or Rendezvous and Proximity Operations

The Pure Coordination ACE covers mutually desirable rendezvous and proximity operations in space, such as the docking of a supply vessel to the International Space Station. While the orbital dynamics and control theory of such an endeavor present a technological hurdle, the game-theoretic considerations are quite simple and require only sound communication. The Matching Pennies ACE addresses situations in which one agent desires the proximate interaction and the other agent desires the opposite. In a pertinent situation concerning the optimal pursuit of a spacecraft by a piece of space debris, David Spendel relied on the field of Differential Game Theory—specifically, the Homicidal Chauffer game-theoretic model.[26]

Space Resource Harvesting as the Stag Hunt

The nascent field of space resource harvesting holds tremendous potential. Lunar extraction may yield nuclear fusion fuel and rare earth metals with important technological and industrial uses on Earth. Near-earth object chondrites and achondrites may yield valuable resources for *in situ* utilization by manned missions or high-value precious metals.[27] Given the Stag Hunt ACE framework, synergistic cooperation in the harvesting of these resources may occur naturally. In cases where there are barriers to such cooperation, an agent (acting as a game designer) may use game-theoretic system design to exogenously change the structure of the game. The agent translates the strategic form game to an extensive form information set and adds a new branch on the previous node. This new course of action strikes a balance in individual utility between synergistic cooperation and the preexisting choice to not cooperate. The respective agent will never use this new branch so long as the other agent demonstrates forward induction through the *a priori* commitment to synergistic cooperation. Perhaps counterintuitively, the more developed an entity's capacity for previous space resource harvesting, the greater trust other agents will place in that entity's commitment to cooperation. Therefore, early US investment in space resource harvesting may incur a beneficial positive feedback cycle.

Stoplight and Correlated Equilibrium

The Stoplight ACE encompasses the Stoplight, Volunteer's Dilemma, and Battle of the Sexes game-theoretic models. The respective space analogs of these models are cooperative maneuvering to avoid a collision, international policing in space, and harvesting space resources in one of two locations where the utility payoff for each agent is different based on the location. Correlated equilibrium provides a natural and beneficial heuristic solution for the challenges posed in this ACE. The type of mechanism used for correlated equilibrium (e.g., memorandum of understanding alternating decision power or an international third party) is immaterial as long as all players view the mechanism as fair and effective.

Chicken as High-Cost Conflict or Intimidation

The Chicken ACE manifests itself as a high-cost Hawk-Dove game-theoretic model. The space analog presents itself in one of two ways: two spacefaring entities with spacecraft on a collision course where neither will maneuver or the impending large-scale conflict between two nations encompassing the space domain. There are several game-theoretic system design approaches capable of addressing the Chicken ACE. Similar to the Stag Hunt, a game designer may exogenously translate the game into extensive form and add a branch to the previous node. This new branch acts as a commitment mechanism that turns an incredible threat into a credible threat (much like the concept of burning bridges). The commitment mechanism may exist in a technological form (a doomsday device serves as a sensational example) or in a diplomatic-political form (such as the use of a "red line"). The strength of this approach rests in the strength of the commitment mechanism; for example, if other agents do not believe in the credibility of a player's red line, the approach will falter. To preserve credibility, red lines must be enforced even when doing so seems impractical since a failed red-line strategy will impact an agent's credibility in any future game against a player with knowledge of the unenforced red line. If a player is unwilling to follow through with the red-line threat, the player should consider not making the red-line threat in the first place.

Another game-theoretic system design approach drives the hypothetical mutual cost of conflict so high that the comparative statics indicate that the two agents would never enter into such a conflict. Quintessentially, the space-contextual application for such an approach would be the commitment by two or more nations to disregard the Outer Space Treaty and commit to the use of nuclear weapons in space should a conflict ever occur.

A final game-theoretic system design approach encompasses an agent that reduces the individual cost of conflict or collision. If the two agents play the mixed-strategy Nash equilibrium, this approach will work to the detriment of the agent using this method. However, this approach improves the probability that the two agents will transition to the pure-strategy Nash equilibrium favorable to the player that used this taxonomy. In the space domain, a nation might enact this approach by developing lower-cost, less reliable, and less exquisite spacecraft, which the nation can affordably replenish in the event of a collision or malfunction.

Conclusion

This article asserted that decision-makers could use game-theoretic system design to understand space power challenges and opportunities better, as well as achieve better outcomes for the US space enterprise. In support of this thesis, we contextualized the spectrum of agent strategic interactions, proposed a new taxonomy for the classification of game-theoretic models, and expounded the proposed taxonomy, using eight atomic game structures with pertinent space applications. In this effort, we strive for the advancement of strategic thinking in the space domain for the enhancement of the US space security posture. ✪

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