Quantifying Information Advantage to Enable Decision Dominance

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Executive Summary

Information advantage (IA) is a critical function to enable Commanders to make decisions that accomplish strategic objectives. We proffer that the combination of a provided data advantage (DA) and a decision maker's situational awareness (SA) allows an organization to achieve the relative IA necessary for decision dominance (DD). Thus, providing a useful decision space model to measure both DA and SA allows one to quantify IA in order to enable DD. In this paper, we provide a background literature review, propose our own definitions for several characteristics and subsets of DD, propose a preliminary framework for measuring DD, propose a series of characteristics that, with a number of assumptions and simplifying factors, can be mathematically represented for a DD score, and propose a use case to test a proposed model against. We also propose several areas for future iterations of this work that may be of interest to the community.

1 Introduction

"If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle."[10]

Having a better understanding of the environment, information, and state of military operations has always been critical in warfare as it allows leaders to make informed decisions with the necessary situational awareness to maximize the possibility to achieve their objectives. Traditionally, this understanding has been focused on the physical realm (troops, maneuver, logistics, etc.), allowing for a direct observation of the battle space and more immediate decision ramifications. However, with the recent expansion of the digital domain, organizations now have the challenge to access, process, store, and analyze data at a never-before-seen scale and pace. Optimizing our processes while understanding our enemies' processes for information permits new ways of understanding.

Several papers have been written about how information advantage (IA) and decision dominance are critical for achieving the required environmental understanding for successful operations[4, 8, 6]. Yet, the U.S. military does not have a framework for *measuring* IA — as a component of decision dominance — or even a largely agreed-upon definition for concepts like 'decision dominance.' This lack of consensus in the cyberspace domain has led to many key stakeholders conflating IA and decision dominance and broadening the already wide scope of the terminology. One proposed definition for IA is "a condition of relative advantage that enables a more complete operational picture and leads to decision dominance — the sensing, understanding, deciding, and acting faster and more effectively than the adversary" [8].

The given definition highlights the importance of speed of information access and understanding relative to the adversary, but fails to provide any real mechanism for measuring IA and implies a overly-simplistic causal effect on decision dominance (e.g., having an information advantage relative to an adversary alone implies that you have decision dominance over that adversary). Additionally, Army Cyber leadership currently list five tasks as essential in gaining and maintaining IA: enable decision making, protect friendly information, inform and educate domestic audiences, inform and influence international audiences, and conduct information warfare [5]. While each of these tasks is a necessary component of IA, its not clear if they are sufficient for IA and how they relate decision dominance.

1.1 Key Definitions and Concepts

In what follows, we propose a series of definitions for the concepts often used when discussing the concepts of information advantage and decision dominance. Our purpose in proposing these definitions is to capture these concepts and their relationships in a manner that is quantifiable. From these necessary qualities, decision dominance can be seen as the ability of an organization to sustain relative information advantage over time. We note that these qualities are necessary, but not sufficient to achieve decision dominance. Descriptions of these qualities are given below.

- **Information Advantage (IA)**: IA is a temporary condition in which an organization can combine a data advantage and situational awareness to completely and accurately define their current decision space. This definition follows from the existing doctrinal model for the relationship between data and information. If information is contextualized and synthesized data, it follows that a data advantage plus situational awareness would lead to an information advantage. This logic lends itself well to quantification as we can then measure constituent elements, DA and SA as defined below, to understand if we are in a condition of IA.

- **Data Advantage (DA)**: DA is a condition in which an organization can collect, clean, correlate, and deliver all data necessary for a decision maker.

- **Situational Awareness (SA)**: SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future [3].

- **Decision Space**: The space of all **plausible** actions that an actor can make. This space is naturally influenced by the information at that actor's disposal and the context — both internal and external to the actor — in which that actor is making those decisions.
- **Decision Dominance**: A state of being able to make more informed decisions than any adversary. Five necessary qualities of decision dominance include data advantage, situational awareness, information advantage, decision space preservation, and decision timing.
- **Decision Space Preservation**: Decision Space Preservation is the ability of an organization to take a given decision space and preserve or expand favorable decision options against degradation. The degradation of the decision space could be a result of adversary action, changes in the context, or the passage of time.
- **Decision Timing**: Decisions have a distinct temporal quality to them. A decision made at the right time can greatly impact the possibility of a successful outcome from that decision. As an example, consider the decision faced by a river dam power operator that is experiencing an extreme rainfall event. The rainfall will cause the water behind the dam to swell to a point where it could destroy the dam. At the same time, if the operator releases water from the dam, downstream environments and communities could suffer from flooding. So, the operator faces a decision of whether to release water from the dam or not. If the decision is made too early to release water from the dam, damage could unnecessarily be done downstream as it's uncertain whether the water behind the dam would have swelled to dangerous levels. Conversely, if the operator waits too long to make the decision to release water, the dam could fail with catastrophic consequences. Thus, the operator must time their decision carefully. Additionally, the presences of certain decisions for an actor are also time-bound; any given decision only exists for certain a duration of time, which duration could be one time or cyclical in nature. To use the aforementioned example, the decision to release water from the dam or not only exists as the swelling situation and the dam exist. Thus, the decision has a duration of existence only while the extreme rain event is occurring and only while the dam continues to exist. Decision timing is a necessary quality of decision advantage as the decisions only exist at certain points in and the success of any given decision is influenced by when that decision is made.

  Time also forms an important axis of the decision space. Once an actor has been able to achieve situation awareness, and thereby knowledge of their plausible decisions as well as possible future states, they then position possible decisions over time to create the decision space. This allows an actor to assemble current decisions and projected decisions together over time to achieve their goal(s) into a *decision path* through the decision space. An example within a military context of a decision path would be an operational plan; an operational plan consists of a series of actions and decision points arrayed over phases, or the time, of an operation taking place. Thus, once again decision timing is important to decision dominance as decision dominance requires sustained quality decisions over time. An important observation about decision timing arises from the previous point: decision *speed* has a unique part in decision timing for decision dominance. The ability to make decisions faster than an adversary results in actions that will then change the decision space for an adversary, which thus causes them to have to reassess their decision path to address the new reality created by the execution of the friendly decision. In other words, the ability to make decisions faster than an adversary forces an adversary into our "decision loop" and out of theirs.

As we developed these definitions and our model we made several assumptions. First, we assumed that actors will prioritize decisions that move them toward achieving their most important objective; friendly and adversarial forces make decisions with the aim of reaching at least one of their objectives, which will typically deny the other of their objectives. This is an assumption that actors will make rational decisions in response to the information they are provided and are able to successfully perform goal valuation prior to making decisions. Goal valuation includes the ability to identify all of an actor's goals, which may be competing, and select those goals which are either most beneficial or least harmful to the actor. Second, we assumed that a decision made by a rational actor would achieve the desired outcomes. This assumption was necessary to decouple the quality of the decision from the quality of the outcome. In practice we acknowledge that a correct decision can fail to achieve the desired outcome for a variety of reasons, however we felt that was outside the scope of the current work.

This paper is structured as follows. In Section 2, we highlight relevant literature in regard to decision dominance, including approaches to measuring IA in terms of situational awareness/understanding and sense-making. In Section 3, we propose a framework as a way forward for IA modeling to enable decision dominance. In Section 4, we discuss opportunities for future work, while providing some concluding comments in Section 5.

2 Literature Review

IA is a multi-faceted concept which, depending on the source, relies on the two interconnected tasks - the ability to sense, assess, and make decisions at speed, while also influencing our adversaries ability to do so. These two related tasks occur in a continuous environment that both need to be measured to fully understand our relative advantage or disadvantage in the decision space. While there has been relatively little literature quantifying or measuring IA, there is research in situational awareness, which may be relevant as a proxy to measuring our relative advantage or disadvantage in the decision space. While a topic of academic debate, a proposed definition for SA is "the term given to the awareness that an individual has of a situation, an operator's dynamic understanding of what is going on" [7]. The broadness of this definition fails to provide the needed framework for any applications to IA. Nevertheless, Mica Endsley proposes a three-level hierarchical model for framing SA that may prove fruitful when decomposing how we quantify IA [3].

The first level of SA, **perception**, is “Perception of the Elements in the Environment,” meaning the ability to perceive the “status, attributes, and dynamics of relevant elements in the environment” [3]. In the information space, this could include perception of data points from news sources, social media, or local leaders. The second level of SA, **comprehension**, is “Comprehension of the Current Situation.” Comprehension SA allows a decision maker to form a holistic picture of an environment based off of the combination of elements in the environment and their significance. The ability to combine data points from disparate sources to gain a better understanding of the environment is crucial for IA space, particularly for a commander’s understanding of the environment. The third level of SA, **projection**, is “Projection of Future Status,” meaning the “ability to project future actions of the elements in the environment - at least in the very near term” [3]. Figure 1 depicts Endsley’s three level SA model.

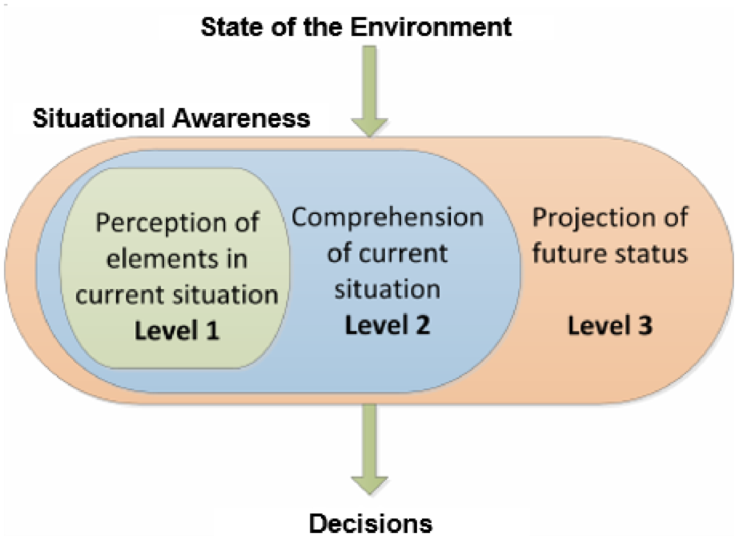

Figure 1: Visual depiction of Endsley’s three-level situational awareness model [1].

The ability to project future status through a greater understanding of the environment is used by humans and machines everyday, both consciously and subconsciously. The decision a Platoon Leader makes to take a different route due to the absence of kids who normally play outside (Perception) is the synthesis of an atmospheric condition with experience (Comprehension) informing a potential future event (Projection). In a similar manner, using news, sentiment, and historical trends to predict future stock prices for quantitative trading is humans using machines to gain greater SA through multiple relevant elements in the environment to project short term future status.

Endsley’s three-level model is helpful in the IA realm as it relies on more than how a subject perceives the environment. Instead, he emphasizes the greater understanding of an environment that an individual can gain from the combination and interaction of variables within that environment, as well as what that interaction by variables means for future events. Endsley also makes the point that the more experience, training, and education a subject has in the related environment increases their ability to understand the environment. In some fields measuring SA is relatively straightforward. For instance, in quantitative trading, an easy proxy for measuring SA success is return on investment. In the IA and decision dominance concepts, however, our relative advantage compared to the adversary is much harder to quantify and requires multiple atmospheric inputs that may not all be native to the digital domain.

There are five proposed SA measurement techniques: 1) freeze probe recall techniques, 2) real-time probe techniques, 3) post trial subjective rating techniques, 4) observer rating techniques, and 5) process indices [7]. The problem with applying any of the techniques to our problem set is that they aim to measure an individual's understanding of their surrounding environment through questions or performance measures specific to that environment instead of the impact of different environmental variables on the subject. Consequently, these measurement techniques quantify the individual's performance on a pre-determined environment as opposed to how environmental changes or the addition of information can better enable the individuals decision making performance. In other words, most SA quantification methods work in the wrong direction for IA; they focus on how the individual assesses the environment rather than how the environment influences the individual's assessment.

Some research has been done introducing two separate environments and measuring the impact on SA for a similar task. For example, Velagapudi et al. theorized that pilots of unmanned aerial systems may perform differently when flying while being in a field environment with complex environmental variables as opposed to a lab environment minimal environmental variables [11]. Such a technique of isolating variables and testing decisions would prove difficult in the cyberspace domain and information environment as the amount of potential variables is near-infinite and testing opportunities are limited due to constant real-world requirements.

2.1 Decision Quality in a Complex Environment

Using Endsley's three-level model of SA, we know that accurate projection is the culmination of situational awareness, which would enable decision dominance. Projection relies on the two lower levels of SA: perception and comprehension. In order to project, we must first succeed in maximizing our ability to both perceive and comprehend the environment. We can enable perception with high quality data (data advantage) presented in a common operating picture and comprehension through mechanisms for collaboration between actors, and both through appropriate training and experience.

Through an analysis of emergency management, Kristine Steen-Tveit and Bjørn Erik Munkvold provide a methodology of maximizing shared awareness through a common operational picture. Steen-Tveit and Munkvold argue that a successful common operating picture (COP) is essential in allowing all team members to perceive the same baseline information by combining both static and dynamic information [9]. An important finding by Steen-Tveit and Munkvold was that information overload resulted in poor simple mental models (SMM), which led to worsened decision making. Moreover, when presented with the same terms, actors had different understandings and responses which impacted processes. COPs must be flexible enough to incorporate information from changing environments and allow for collaboration while simultaneously avoiding over-complication to account for the human mental process [9]. Steen-Tviet and Munkvold also cover how experience in a related scenario impacts decision-making. Actors have two systems that impact the decision-making process. The first is unconscious and instinctual, relying on previous experience to choose an optimal action. The second system is more deliberate and logical, enabling the comparison of different alternatives and resulting in a choice more adapted to the specific environment. The Recognition-Primed Decision (RPD) model demonstrates how experts make decisions relying on both systems. Experts use previous experience to make an accurate situational assessment (system 1), and then conducting a mental simulation of events for an optimal choice (system 2). The RDP model enables optimal decision-making in time sensitive operational scenarios [9].

A COP provides the "common-picture" necessary for Level 1 SA; however, more information and experience is need for Level 2, comprehension. One suggested method by Steen-Tviet and Munkvold is to create a "trading zone" where actors with different expertise can have a dialogue on what they gained from the COP, resulting in a collective sense-making of the situation allowing for a common situational awareness. Such a trading zone could take place as a staff meeting where experts in personnel, intelligence, operations, logistics, strategy, communications, and information operations provide input to a Commander in an effort to create a shared awareness based off of experience and expertise. This could also take place in a chatroom allowing for real-time updates, constant communication, and flexibility to provide input.

In the cyberspace domain, communication structure is critical as subject-matter experts may not have the same lens or vernacular as policy makers and planners. A communication structure will allow decision makers to avoid information overload from the variety of input vectors to which he or she is exposed. Ideally, experts and policy makers can develop a common situational understanding for a decision maker. Those experts are responsible for distilling copious amount of information down to the most relevant and salient points without oversimplifying the complexity of a problem. A decision maker then can use their experience and intuition to project what decision leads to an optimal result. Figure 2 displays how a COP can help provide a common situational understanding.

2.2 Decision Velocity in a Complex Environment

Decision dominance is a zero-sum game, where advantage in the space is relative to our adversaries' positions. In order to gain an advantage in the decision space, we need to make a decision that gets us closer to our primary end objective(s) (a quality decision) with the right timing, which prevents an enemy from being able to make a decision to get to theirs. In a continuous complex decision making game, the speed of the decision has the potential to be as important as the decision itself, or put by General George S. Patton, "A good plan, violently executed now, is better than a perfect plan next week."

An interesting corollary to the challenges of making decisions in the digital domain of

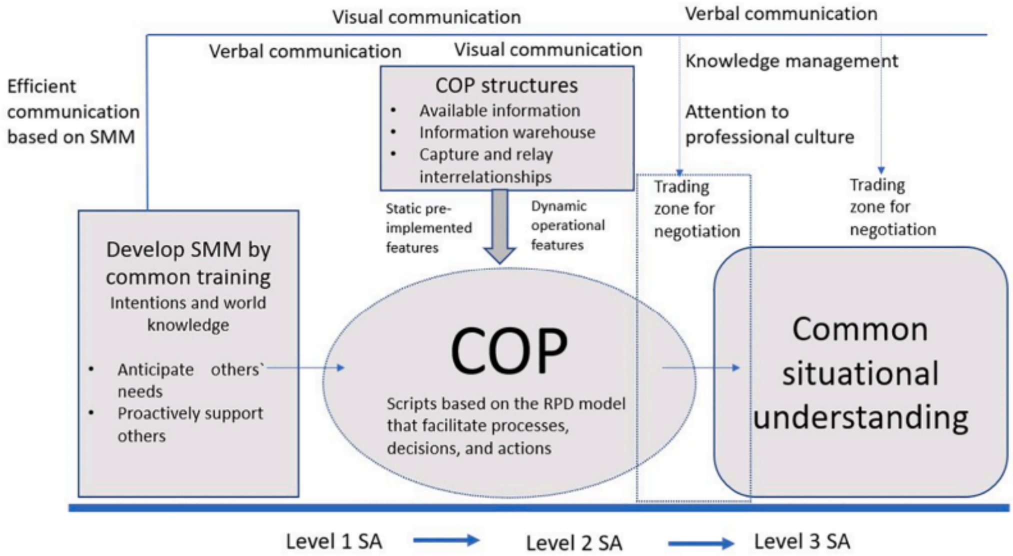

Figure 2: Conceptual framework from Steen-Tviet and Munkvold for using a COP as a baseline assessment to achieve common situational understanding.

cyberspace is the microcomputer industry in the 1980s. Like cyberspace operations, the microcomputer industry rapidly changed due to rapid technical innovation over a short period of time. Kathleen Eisenhardt studied the impact of making fast strategic decisions in the microcomputer industry and associated high-velocity environments. She forms five main propositions in her findings (Figure 3) that increased speed in the strategic decision making process: 1) greater use of real-time information, 2) the greater the number of alternatives considered simultaneously, 3) the greater the use of experienced counselors, 4)the greater the use of active conflict resolution, and 5) greater integration among decisions [2]. The resulting increased speed also resulted in a measured increased performance. Many of the themes in her research are solved by the institution of a successful COP and trading zone such as integration, real-time information discussion, and venue for conflict resolution.

3 Preliminary Modeling

In what follows, we propose a possible quantitative framework for IA decision space modeling that uses a scoring system to quantify IA with the goal to help enable decision dominance. In the course of this work, the group developed several variations of the model. Those alternates are discussed in the Appendix. The framework we present here is still conceptual in nature and would require significant research work to both determine its suitability and feasibility for implementation with actual data. As an important note, in this framework we assume that decisions made by an actor are rational, meaning in their best interest, given the information they are aware of. To begin defining the model,

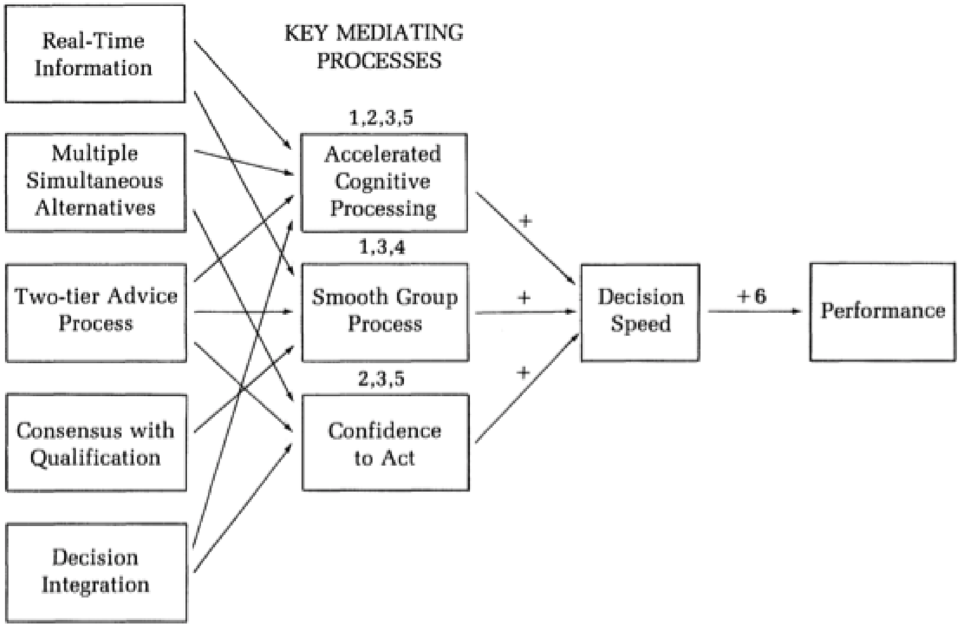

Figure 3: Eisenhardt's proposed model for strategic decision speed in high-velocity environments.

we first characterize an actor's decisions in one of three ways. A decision made with the ability to 1) attune to the appropriate/relevant sources of information, 2) integrate sources of information to create an accurate and holistic understanding, and 3) project and utilize an accurate decision space based upon the previous holistic understanding results in a positive score. A decision that is based upon a decision space that perfectly projects the future with absolute certainty made in a rational manner would receive a maximal positive value. A decision influenced by your adversary or that otherwise moves you away from your primary objective(s) would receive a negative score. An incorrect decision made with incorrect information which would move the actor as far away from their objective(s) as possible would receive a maximal negative value. The lack of a decision or a decision made with no information would receive the expected value of the scenario with a neutral score. Figure 4 depicts the proposed framework.

This decision dominance framework is a continuous game of competition where decision dominance is achieved through sustained information advantage. Now that we have a framework for characterization of decision dominance, we can investigate a method for measuring information advantage. In Figure 5 we suggest a network where a series of functions can be imposed to quantify information advantage. Our network has two primary components for quantifying relative information advantage.

The first primary component for information advantage we identified is data advantage. The data advantage is necessary to provide the best possible picture of a situation for decision makers to evaluate. We used the 5 v's (variety, veracity, velocity, value, and volume) of big data to evaluate our quality of data and advantage or disadvantage

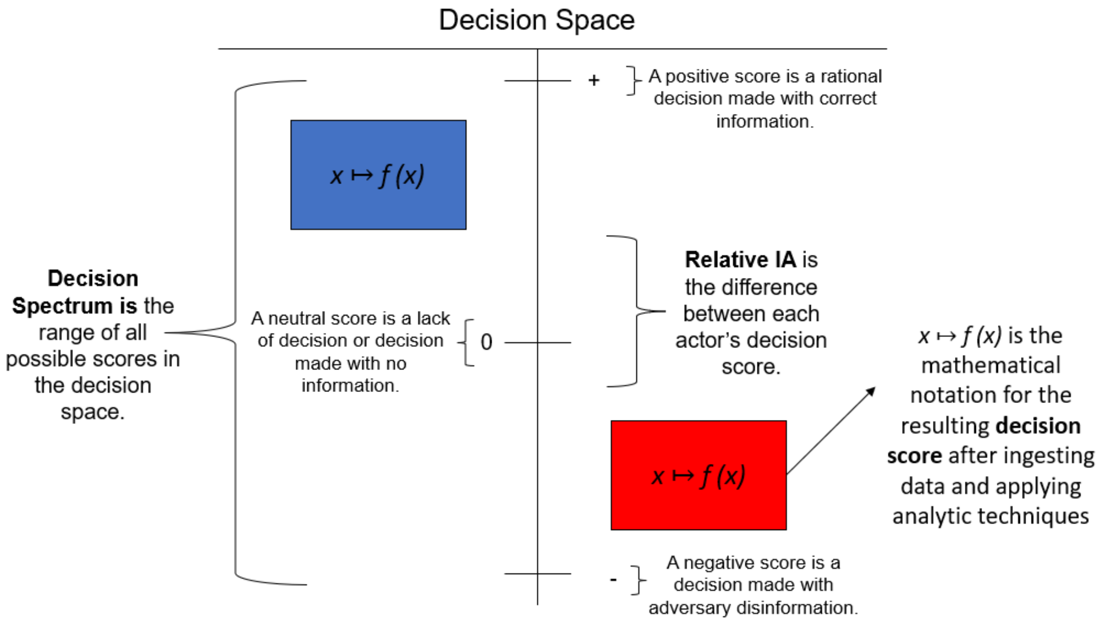

Figure 4: Our proposed framework for IA decision space modeling to achieve decision dominance.

relative to an adversary. We also proposed some factors that could influence each of the v's individually.

The second main component is the situational awareness of the decision maker, meaning their ability to perceive, comprehend, and then project the decision outcome based on the data he or she is being provided. Factors such as probabilistic uncertainty, education, training, experience, and situational complexity have an effect on how the data is evaluated as well as the ability for a decision maker to achieve a situational awareness level of accurate projection. The decision that would lead to a decision maker completing their objective must also be available to the decision maker and directly impacts their situational awareness due to constraints on the decision space and projection ability. Several factors could effect decision availability such as timing, orders, or regulations.

Evaluating the outputs of the quality of our data as well as a decision maker's situational awareness would allow us to evaluate where in the decision space we lie and if we have achieved relative information advantage. Further modeling would be necessary to model how momentary relative information advantage accrues over time into decision dominance.

3.1 Possible Scenarios for Investigation

One suggested use case to evaluate our model is deleting users who associate with extremist groups off of social media platforms. By allowing extremist social media users to continue using mainstream platforms, they have the potential for a much wider reach for

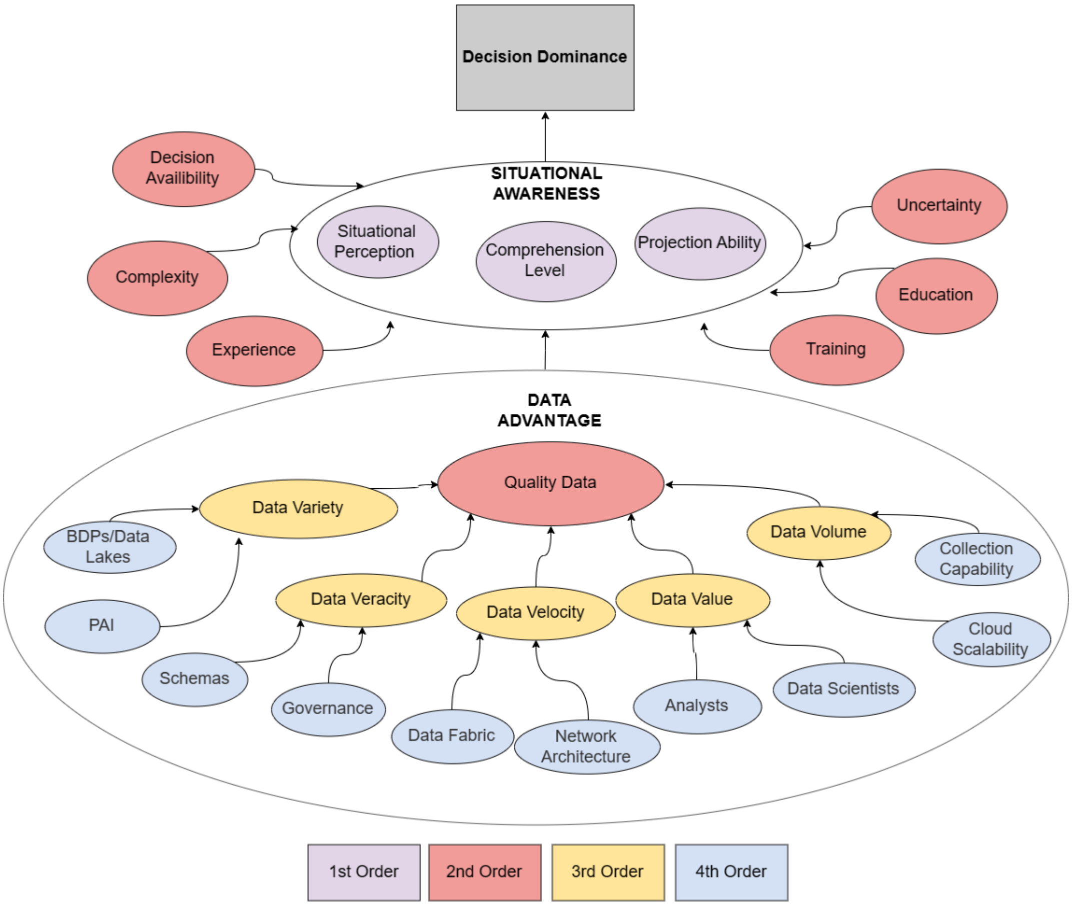

Figure 5: A decision dominance network for the purpose of eventual numerical output.

their message; however, the population susceptible to the messaging is diluted and also exposed to competing messaging. Beyond this, it is easy for intelligence agencies and law enforcement to track mainstream social media platforms for planned events as well as reporting of sensitive content to social media companies for easy removal. When a social media site bans an extremist user, he or she is often likely to migrate to a different media platform with less stringent enforcement of rules and a more extremist population. Unregulated content posting allows for an echo chamber of extremist view points; thus, radicalizing an individual even further. These further radicalized individuals are more likely to plan extremist events that effect the general populace; however, they have a significantly reduced ability to expose the general public to their ideology via the digital domain. We propose that there is an optimal point of banning social media users given how far towards extremist ideology they have migrated (levels of misinformation and/or harmful content spread), their social media audience (number and type of followers), and outside events that are particularly sensitive (elections, war, social movements) while considering that leaving unregulated social media users on mainstream sights allows mainstream sights to become more extreme as well. The dichotomy of social media usage is referenced in Figure 6.

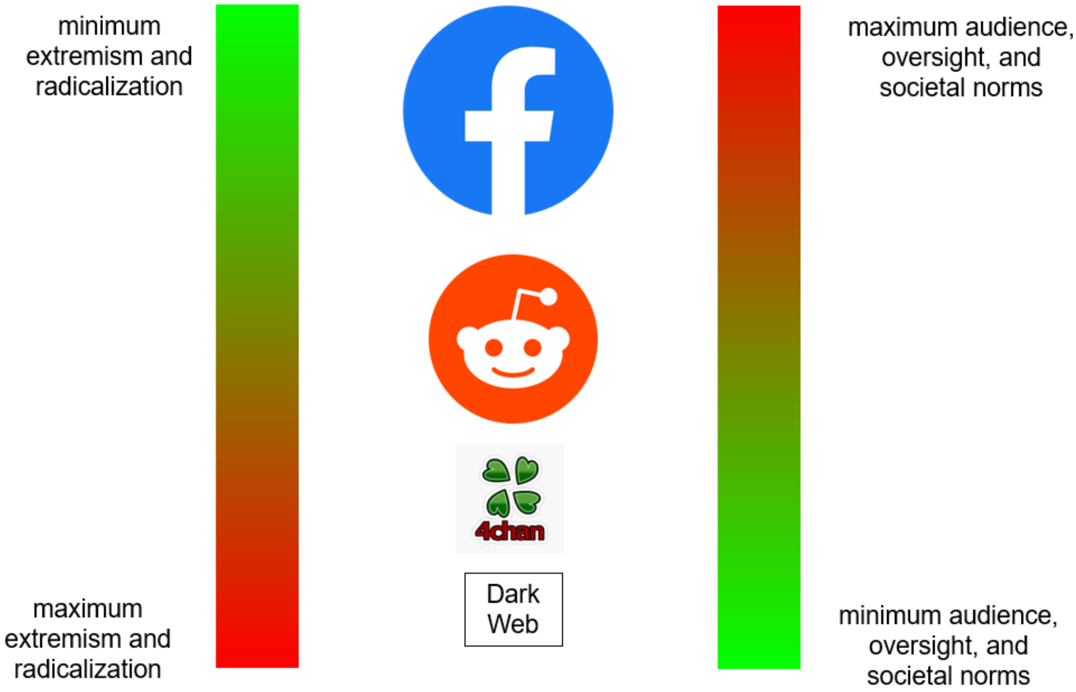

Figure 6: Dichotomy of social media usage and extremist movements.

We can use our decision dominance model with our decision space framework to evaluate the combating extremist ideology in the digital domain.

4 Future Work

Future work could include assigning mathematical functions to our decision dominance framework to allow for a numerical output, as well as an empirically-based understanding of which components of decision dominance have the most variance and impact. A potential method for using this is using the social media extremism framework and evaluating our quality of data for making decisions in the decision space, as well as the situational awareness of actors who have traditionally needed to make the ban or not ban decision and what those outcomes were.

A second study could also be done to evaluate decision dominance theory using a framework of continuous and infinite games of imperfect or partial information, where each decision is modeled as a matrix of probabilistic outcomes. Such a study could include designing a strategy for maximizing expected output, while mitigating risks. The idea of this would be to model what an optimal decision strategy in probabilistic methods looks like.

A third recommendation for future work would be to implement a multi-objective optimization function on our first use case. Two potential objectives in our model could be minimizing spread of information while maximizing actor rehabilitation through exposure to societal norms. Such a study would lie mostly in the information domain and how actors rehabilitate, spread, or continue to migrate towards extremism.

A fourth area of future work would be a study of the suitability of different models in different contexts. For example, is information advantage and decision dominance modeled differently in a strategic context than in a tactical context? Can the model be applied in a real-time operational context or would it be better utilized as a training aid or are there some components that can be utilized in both contexts? Does the model need to be adapted different phases of the conflict continuum - from competition to armed conflict? Perhaps the model remains unchanged but different weights are applied to the features of the model based on the context. Such a study would explore these questions and make recommendations to guide the application of models to the appropriate situations.

Finally, in our Appendix 1 we detail critical points of unresolved discussion on this topic. A follow on paper further exploring the intricacies of our definitions and conflicts over problem framing would provide value for future discussions and problem-framing efforts. Moreover, we highlight some alternative models to consider in Appendix 2.

5 Conclusion and Recommendations

Information advantage is a critical function to enable Commanders to make decisions that accomplish strategic objectives. The combination of a provided data advantage and a decision makers situational awareness allows an organization to achieve the relative information advantage necessary for decision dominance. We believe it is important to provide a useful model for how we measure both situational awareness and data advantage as each is a critical component of IA and organizations maximizing their operational capabilities. Throughout this paper, we provided a background literature review, proposed our own definitions for several characteristics and subsets of decision dominance, proposed a preliminary framework for measuring decision dominance, proposed a series of characteristics that, with a number of assumptions and simplifying factors, can be mathematically represented for a decision dominance score, and proposed a use case to test a proposed model against. We also proposed several areas for future iterations of this work that may be of interest to the community.

From this preliminary investigation, we have a number of recommendations. First, we recommend further study into both the conceptual underpinnings and how one might computationally model the *decision space*. As part of this investigation, we found that the decision space tends to be the most important, unknown factor in decision dominance. Since we can often assume an actor will act rationally given their known objective, current decisions, and projected future states and decisions (i.e., the decision space), the nature of the decision space becomes the critical enabler to decision dominance. At this time, however, it's not clear how to model or conceptualize the decision space in the open-ended and frequently unique scenarios that confront military decision-makers. Second, we recommend further study into a better means of measuring data coverage. From our investigation, it is clear that data quality — and its corollary of human understanding of data — is a critical enabler of decision dominance. What is less clear is how one can measure data quality and communicate that effectively to a decision-maker.

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Appendix 1: Areas of Unresolved Discussion

Over the course of this paper, the authors had several discussions and points of friction that were both unresolved, given the current state of knowledge, and critical in the understanding of decision dominance. This appendix is dedicated to documenting those topics for future iterations of this work and to continuing discussion.

A main point of discussion throughout this paper was if making decisions with speed added value to decision dominance. One argument from the authors was that making decisions faster allowed for an advantage over an enemy as you altered their decision space faster than they could make decisions. Also, if each "good" decision made moves an actor closer to an end objective, then the actor is achieving dominance with speed relative to their adversary. A counterargument made throughout the paper was that by exercising "tactical patience" an actor may have the opportunity to make a different decision and that making the right decision at the right time was more important than making the decision as quickly as possible.

A second point of discussion throughout the writing of this paper was the nature of time in regards to decision dominance. One argument made was that advantage in the decision space must be maintained for a sustained period in order to achieve "dominance," otherwise an actor and their adversary are in competition throughout the decision space; therefore, neither actor can meet the criteria of dominance as both have periodic advantages. A counterargument was made that as long as an actor has an advantage in the decision space at the time of decision implementation then that actor has the temporary dominance needed to make a decision. A follow on thought by the group was that perhaps the second meaning of decision dominance was actually "decision sufficiency." Decision sufficiency may not be relative to an adversary, but instead means an actor has the necessary information to make a decision. It follows that decision sufficiency in operations would likely be the criteria for implementing a decision and decision dominance is something the actor should strive for, but may be unable to achieve or even know if they have achieved due to the inability or uncertainty in assessing an adversary.

A third point of friction over several discussions was if decision dominance fit the description of a zero-sum game. One side of the discussion felt that dominance was relative to other actors in the decision space; therefore, any advantage or gain one actor had was a disadvantage for their adversaries. A second opinion was that dominance meant that all of the information needed to make a decision was present and that the accumulation of the necessary information for a decision was not relative to an adversary.

A fourth point of discussion was the utility of applying a rational actor assumption to our model. One side argued that this is a reasonable assumption as friendly and adversarial forces will naturally make decisions with the goal of reaching their desired objectives. As such, stating this as an assumption is both accurate and helps readers conceptualize the role of actors in the model. The counter-argument highlighted that applying a rational actor assumption obviated the situational awareness component of the model as it essentially assumes accurate projection. By applying this assumption the model collapses to measuring relative data advantage and is therefore less complete.

A final point of friction over decision dominance was the degree to which an empirically-based, computational model can be constructed that can indicate decision dominance. One of the salient points of making any decision was that the nature of the *decision maker*, and their inherent tendencies, cannot be ignored when measuring or evaluating decision dominance. This implies that even if every element of information on a battlefield could be quantified into digital data, it's still not possible to construct a computational model that can objectively indicate decision dominance. Thus, there was disagreement between the group over how much, or what portions, of the decision space could actually be mathematically modeled for computation. While we have proposed the beginnings of a mathematical model that can tackle this latter problem, we still very much acknowledge that the ability to produce a computational model for all or some aspects of decision dominance remains a point for future research and discussion.

The above-listed points of debate are examples of the complexity and intricacies of defining a framework to measure decision dominance upon and present just a few — albeit the most salient to the conclusions of this article — of several differing viewpoints regarding decision dominance topics. For the purposes of this paper and building an initial framework, it was necessary to make assumptions regarding our implementation, but we hope that this appendix serves as a starting point for future conversations around the topic.

Appendix 2: Alternative Models

One alternative model stemmed from discussion above regarding the rational actor assumption. The argument was that, given the rational actor assumption, what we are really modeling is not so much the decision but the decision space itself. An actor, by our Endsley interpretation, essentially constructs the decision space based on the environmental inputs and their subjective end puts and then decides from that decision space. With a rational actor, if they can construct a reasonable approximation to the true decision space (which seems like it is infinite and must be approximated, and, basically, unknowable), they will then make the appropriate decisions within that space. However, if they are unable to construct a good approximation of the decision space, either due to adversary interference, lack of information, attunement to bad information, etc., then their rational decision could actually lead them toward a bad decision. This model, in contrast to the systems dynamics model above, would simply measure the accuracy of the decision space that an actor is able to generate.

A second alternative model stemmed from the discussion on both the rational actor assumption and the role of speed in the model. This model adopted the view that inputs to IA are DA and SA and the output of IA is the decision space. In this model, DA and SA could be evaluated as they are in the primary model along with the quality and completeness of the resulting decision space. The decision space that is the output of the IA model is then the input it a separate decision dominance model. This DD model would adopt a timing oriented perspective as opposed to speed oriented. In this model, DD would be evaluated by an actors ability to preserve their decision space until such time as they chose to act. This could present in the simplest case as a binary answer to the question "was the actor able to make the decision that they wanted to?". If not, their decision was affected (or dominated) either by time or the adversary and thus they failed to achieve decision dominance. Once a given decision has been made, the cycle restarts with pursuing IA to define the new decision space. In this model speed still plays a role in that the decision space is subject to erosion and manipulation over time, however it also allows for the possibility that new options could present themselves through patience. In other words, the decision space could also expand over time which would be missed through the pursuit of speed. Further, this model allows for the possibility that an actor may not have a positive decision available to them. In the primary model, this would result in a negative evaluation of IA and DD. This model would argue that we would still want to capture a positive IA and DD in that the actor had the right understanding of the decision space (IA) and that they were able to make the best choice available in the bad situation (DD). Finally, this model does not adopt the zero-sum framing of the primary model, and therefore would define DD entirely in internal terms. This has the benefit of being easier to measure as it avoids including the uncertainty of trying to measure the adversary's decision space while still accounting for the fact that the enemy gets a vote.