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The Pursuit of Optimization in the People's Liberation Army Operational Planning Research: Patterns and Implications

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"Fight no battle unprepared, fight no battle you are not sure of winning. Make every effort to be well prepared for each battle, make every effort to ensure victory in the given set of conditions between the enemy and ourselves." -- Mao Zedong[1]

Executive Summary

The People's Liberation Army (PLA) is more than two decades invested in developing deeply methodological and mathematical approaches to managing war. Consistent with overall Central Military Commission guidance to prepare to fight an informatized and (probably) intelligentized war; with PLA systems warfare doctrine; and with the overarching theories of Effective Control and War Control, operational optimization methodologies appear to be an important means by which to translate these top-level frameworks into operational reality. Although access to the optimization processes in use in the operational PLA is extremely limited, a review of some 80 research papers exploring the development of operational optimization methodologies published by PRC national- and service-level research institutions between 2003 and 2026 provides insights and likely implications for the operational PLA.

The body of research stems from academic institutions, not the operational PLA. The operational PLA is known to use such methodologies, and it continues efforts to improve and upgrade its operational optimization capabilities. While the research builds on real-world challenges in operational optimization, the literature does not indicate which methodologies have entered, or may still enter, operational PLA use. Therefore, this study focuses on several patterns evident across the body of research and the likely implications for operational PLA to be drawn from them.

The first pattern is that the research, in addition to being consistent with long-standing senior guidance and with known PLA practices, has remained thematically consistent for over 25 years. Stemming from authoritative PLA research institutions, this degree of consistency

suggests that this line of effort is responding to a consistent demand signal from the operational PLA for improved and more powerful operational optimization tools. This remains a work in progress.

The next pattern is that the research is evolving into more complex and powerful methodologies to deal with higher-level and more complex operations. The effort appears to have evolved in three phases from the early 2000s to the present. The earliest phase focused on adapting optimization methodologies from non-military problems such as city planning or commercial product development and modifying them for the unique challenges of military operations. This work focused on individual platforms or discrete management challenges of limited scope and scale. In the 2010s, the work turned to layering and sequencing methodologies to deal with more complex operational problems, but still limited to discrete types of operations or individual warfighting domains (air, ground, maritime). The third and most recent phase builds on this layering and sequencing, but adds more advanced algorithms, especially genetic algorithms, and artificial intelligence to optimize operations plans for complex and dynamic combat environments involving joint or combined arms missions and sustained combat operations. Research on optimization tools capable of managing this level of combat is apparently still in its early stages.

Third, tensions remain in the debate about balancing the role of automation and mathematical decision-making with the role of human commanders and staffs. One school appears to see human subjectivity as the single most important impediment to greater levels of optimization, while others recognize that human judgment cannot be removed from the operational decision-making process. Addressing this question, this study extracts indicators from the various levels of optimization methodologies across the literature and identifies where the role of human judgment remains embedded in each level. It concludes that there is no foreseeable possibility of removing human judgment from the process, although the balancing point will almost certainly be dictated by the type of operation, its level of complexity, and the larger operational context.

The study concludes with three implications derived from these patterns. First, these optimization methodologies may significantly reduce the impact of uncertainty in combat operations, or at least may be reducing PLA perceptions of the impact of uncertainty. In addition to optimization, several studies explicitly aim at a calculated means to bound the realm of uncertainty in any given operation and to calculate a range of flexible options to deal with the impact when a risk event does occur. This capability is also implicit in the scale and complexity of the calculations that do not explicitly focus on managing uncertainty and risk.

Next, the research appears to minimize the role of human perception as an enabling factor in deterrent operations targeting the PLA. In the operations optimization methodologies laid out in the research, steps that U.S. or partner nations may take to deter PLA action enter the operational decision-making process as quantified variables, to be weighed against the full range of other variables a PLA commander would have to make. Therefore, for a deterrent action to have an operational impact, it would have to affect the bottom-line calculus so that the PLA commander's courses of action appear to be non-viable. In this approach, effective deterrence is possible but may be a more complicated challenge than anticipated.

The third implication speculates that the relatively immature state of optimization evolution capabilities to be applied to combat operations of high levels of dynamism and complexity may predispose higher-level PLA commanders to plan and execute "short, sharp" wars—more intensely planned operations executed for a limited time and focused on limited objectives in a limited geographic space. This is consistent with Chinese Communist Party (CCP) senior thinking about the importance of limited wartime objectives and costs that are components of both Effective Control and War Control theory.

The paper concludes with thoughts about the long-term impact that more powerful artificial intelligence (AI) tools might have on future PLA operations optimization. This section considers the possibility that future AI tools may change PLA confidence in its ability not only to sustain complex operations, but also to seize and sustain the initiative in war for longer periods and asks whether such a development might lead to future CCP leaders to recalibrate their thinking on the cost-benefit balance of military use.

Introduction

PLA research institutions are more than two decades invested in a deeply methodological and mathematical approach to managing war, probably reflecting a similar approach in the operational PLA.This approach to warfare is a means to systematically define desired objectives, methodically survey the disposition of means to achieve those objectives, and to mathematically calculate from these the most effective ways to advance towards those ends. The PLA approach to operational optimization is overwhelmingly dedicated to extensive mathematical calculations intended to model complex military operations at all levels and offer PLA commanders suggested courses of action, and a means to "scientifically" manage the execution of those operations, ranging from the employment of individual platforms and weapons systems to the prosecution of complex, joint operations.

These efforts are an important aspect of the PLA's thinking about the practical application of modern warfare. They are couched within a larger framework for conceptualizing, planning, and executing modern war, as PRC leaders perceive it. At the highest level, "Systems Warfare" describes the overarching *concept of operations* shaping PLA warfighting doctrine and force posture. Central Military Commission guidance on preparing to fight informatized, and probably also intelligentized, warfare describes the *type* of war they are posturing to fight. Effective Control and War Control Theory provide a framework for *managing the conflict* before, during, and after the kinetic stage. Operational optimization methodologies provide the method for *translating* these concepts, doctrine, and theories into reality.

It is still a work in progress. Analysis of a body of PRC research into various operational optimization methodologies makes that clear, and it describes some of the issues they are trying to overcome. They are experimenting with dozens of methods: modifying them, layering them, and sequencing them in ways the methodologies were never designed for. The methods often don't play well together; the outputs from some methods don't combine well with the outputs of others. There is no apparent linking or nesting mechanism to embed calculations for individual systems into those used to calculate domain- or service-bounded operations, or to blend them into higher-level, complex joint operations. Some methods leave critical operational aspects unaddressed. Follow-on research seeks to amend that. Yet the work continues, and the methodologies evolve into more complex calculations and algorithmic applications based on larger data sets and addressing higher levels of combat operations.

The body of research also indicates that, although the PLA already uses aspects of this "scientific" approach in its operational planning, its ability to apply it in any comprehensive way to complex joint operations is not yet mature. Methods to manage individual systems and specific service- or domain-bounded operations such as sea mine efficiency, ballistic missile target allocation, or air-to-ground attack operations are better developed and more mature after decades of focus and effort, while the methods and algorithms to manage complex, joint operations are still in their early stages of development. As one researcher observed in 2023:

> Although [previous] studies have improved the target weapon allocation model and solution method from different aspects, they all focus on the target allocation of platform- or tactical-level firepower strike missions, with small planning scales and simple constraints. *There is a lack of research on general combat task allocation models, and solutions to problems such as [those involving] large scale decision-space and complex constraints need to be explored*.[2] (Emphasis added)

The algorithm that the operational PLA most commonly uses for combat task allocation, the Multi-Dimensional Dynamic List Scheduling (MDLS) algorithm, has known shortcomings and defects.[3] Nevertheless, it is what they have and so it is what they use, while the research continues to explore ways to improve its efficiency and effectiveness.

In the meantime, research continues to improve the processes. The shortcomings they had a few years ago are not the ones they have now, and the shortcomings they have now will not be the ones they have in the future. At some point, they will reach a threshold of maturity at which PLA operational leaders will have confidence that, on balance, they have sufficient understanding, data, computing power, and mature algorithms they need to drive wartime operations to successful outcomes. To paraphrase Mao Zedong's early guidance to the PLA, quoted at the top of this paper, they will fight prepared and they will fight confident of winning, because they will have made every effort "to ensure victory in the given set of conditions between the enemy and ourselves."

Better understanding of the PLA's journey down this path will be essential to more effective planning to deal with their growing military power. This is a logical supplement to the bodies of work already available examining PLA technological development, force posture and doctrine, and their exploration into the various roles artificial intelligence (AI) could play. Understanding their thinking about the central role that operational optimization methodologies play in operational planning and conflict management sheds light on their thinking about how to efficiently and effectively employ their capabilities.

Methodology and Scope

Information on the actual data sets and software programs that the PLA uses to manage its operations is not available to the public. However, a body of research documenting an evolving approach to operational optimization methodologies spanning more than 20 years is openly accessible. The research stems from academic institutions, not from operational PLA units, although it does contain occasional references to improving methodologies in operational use, confirming that there is some overlap between this work and the actual practices in use in the operational PLA.

This study reviews some 80 research papers prepared for the purpose of providing the operational PLA with improved, more powerful, more capable operational optimization methodologies to "scientifically" calculate success in the complex, rapidly changing world of modern, informatized, intelligent warfare. It identifies the major trends and patterns that run through the body of literature and offers some analysis of potential implications rooted in those trends and patterns.

The papers selected for this study are the work of researchers from authoritative national institutions, including the PLA Academy of Military Sciences, PLA National Defense University, the PLA National University of Defense Technology, and PLA Navy, Air Force, Army, Rocket Force, and Aerospace Force colleges and universities. Some of the work is also from researchers at PRC national level institutions that have histories of supporting military research and development, such as the China Academy of Sciences, Beijing University of Posts and Telecommunications, and the China Electronic Industries Group Corporation. All the papers in this body of literature were published in credible, national-level journals, such as the *Journal of Electronics & Information Technology*, *Journal of the Beijing University of Aeronautics and Astronautics*, *Journal of Systems Simulation, Ordnance Industry Automation*, and the journal *Command, Control & Simulation*, to name a few. A small number of the papers were published as proceedings from credible international organizations, often the Institute of Electrical and Electronics Engineers (IEEE). Roughly 96 percent of the literature reviewed for this study was published in Mandarin, intended for Chinese-speaking audiences.

The scope of this study is limited to methodologies designed for use in the operational PLA. This refers to the military formations that are tasked with the physical expression of military power, ranging from theater command down to the smallest units designated for independent operations, generally battalion level or the equivalent. In Chinese, this level is indicated by the term *zuozhan* (作战) which literally translates to "make war" or "do battle," but which is most commonly rendered in English as "operations," "operational," or "combat." *Zuozhan* generally falls between the level of strategy (*zhanlue*, 战略) and tactics (*zhanshu,* 战术). However, this study found it useful to also consider the level of campaign (*zhanyi*, 战役) as a defining characteristic of *zuozhan* operations. This is because the definition of a campaign, "a series of related major operations aimed at achieving strategic or operational objectives within a given time and space"[4] provides a critical functional relationship between the two, and also because it specifically bounds the execution of both levels to "a given time and space." This functional relationship and the imposition of time and space constraints will be important considerations when analyzing the likely implications of the trends and patterns emerging from the body of literature.

The body of literature ranges from 2003-2026. References to earlier papers on similar topics exist, but ability to access the literature from earlier than 2003 has proven difficult. The scope of research in the body of literature includes all PLA services, including the previous Strategic Support Force and later Aerospace Force, at all levels of operation, from tactical to theater command. It examines the efficiency of individual military systems (e.g., torpedo systems), operations that fall within the realm of single services or warfighting domains (e.g., missile force target allocation or air-to-ground attack operations), and higher-level complex combined arms operations (e.g., island landing campaigns or air- and maritime blockade operations). The research explores the efficient employment and management of existing force posture at the time of the research, as well as newly emerging operational challenges (e.g. urban warfare under intelligent conditions), and challenges in research, design, and production of future capabilities (e.g. planning major aerospace production projects).

This study specifically excludes any papers written for media publication, whether print, broadcast, or online media, on the basis that the purpose of those venues is primarily to propagate PRC government political views. There is potential value in such material because it may reflect actual PLA trends, challenges, and intentions. However, the principal purpose of those articles is popular propaganda, not professional discourse examining the development and application of new technologies and new methodologies. This study focuses only on the body of literature that contains professional discourse on applying "scientific and rational" mathematical methods to resolve complex, real-world warfighting issues.

Setting the Scene: The Evolving Intersection of Mathematics and PLA Military Operations

Assessments of relative military capabilities, strengths, and weaknesses is an indispensable part of operational planning, as it has been throughout the history of military operations. Mathematical formulas entered the process during the First World War, when British engineer Frederic William Lanchester introduced a system of ordinary differential equations (ODE) to calculate force posture requirements for aerial combat. ODE had a history of application in various biological studies, but Lanchester's adaptation was the first attempt to apply ODE, or any systematic mathematical methodology, to evaluate the likelihood of combat success based on forecasting rates of attrition.[5]

Lanchester's methods did not fare well, in part because the early equations were unable to account for the complexity and uncertainty of actual warfare. Nevertheless, analysts continued to apply, evolve, and adapt mathematical processes to military operational assessments.[6] Growing from these roots, systematic analytic methodologies, often referred to as Multi-Criteria Decision Analysis or Multi-Criteria Decision Making (MCDA/MCDM), have become a widespread tool in complex military decision-making around the world today.

The Chinese PLA has been using mathematical estimates of relative force posture and combat attrition forecasts since its years of civil war in the Republic of China, between the end of the Second World War and the establishment of the PRC in 1949. For example, in 1947, considering transition from small unit tactics to large-scale maneuver warfare, PLA leaders developed a five-year plan to defeat their Nationalist rivals, the Kuomintang, based on attrition calculations derived from combat experience fighting Nationalist forces. The plan calculated:

> In the light of our successes in the past two years' fighting and of the general situation as between the enemy and ourselves, [it is possible] in a period of about five years to wipe out a total of some 500 brigades (divisions) of the enemy's regular forces (an average of about 100 brigades a year), to wipe out a total of some 7,500,000 men of his regular and irregular forces and of the special arms (an average of about 1,500,000 men a year), and to overthrow the reactionary rule of the Kuomintang completely.[7]

As it turned out, these calculations were wrong. Rather than five years of attrition warfare, it only took the PLA about 18 months to overthrow the Kuomintang from the time they put this concept into operation.

The difference lay in their transition from war based on limited, local confrontations to large-scale maneuver warfare. In early 1947, when these calculations were made, the PLA had very little experience with this type of fighting, and so was not able to effectively calculate its effect. Once put into practice, PLA leaders quickly adapted their planning processes, learning to effectively calculate relative force postures, strengths, and weaknesses within this new warfighting paradigm. This enabled them to take advantage of unforeseen opportunities that opened during their campaigns against the Nationalists. Their effect was profound. Rather than early steps in a multi-year attrition strategy, as originally intended, the series of reconceived campaigns ran from September 1948 to January 1949 and opened the way for the Communists to defeat the Nationalists at least three years ahead of plan.

Just as the switch to a different form of warfare affected earlier PLA operations calculations, PRC studies of the 1991 Gulf War made clear to Beijing that they were facing a new type of warfare, one of unprecedented speed and complexity, made possible by the skillful application of modern technology.[8] As with the shift to large-scale maneuver warfare in the late 1940s, the PLA had no experience with this form of warfare. They did recognize, however, that the ability to learn and adapt on the battlefield, as they did during the earlier civil war campaigns, would be drastically constrained by the speed and complexity of this new type of conflict. This also meant that the consequences of making mistakes in early operations could be much greater, potentially deciding the outcome of the war at a much earlier stage than was the case in the forms of warfare the PLA had previously prepared for.

These are milestones on the path to the PLA's growing commitment to "scientific" operational planning and conflict management. The PLA adopted its current top-level strategy in 1993, when it established the Military Strategic Guidelines for "Winning Local Wars Under High Technology Conditions," later adjusted to accommodate the evolution of informatized warfare, and the advent of intelligentized warfare. Since then, the emphasis on being able to effectively deal with speed and complexity has only become more intense. Amplifying the PRC government's already-existing institutional culture of "scientific" governance and its explicit emphasis on the centrality of cybernetics to the effort,[9] PLA use of mathematical calculations to inform "scientific" operational planning and conflict management has evolved from what was once a staff tool to what is now increasingly the foundational means to sustain the stable operation of the rapidly unfolding, complex military conflict they anticipate being called on to fight and win.

This raises several questions. To what extent might algorithms and other complex mathematical approaches be advancing actual PLA warfighting capabilities? How might complex mathematical models and algorithmically generated operations plans shape PLA leader thinking about how to use military force? What, exactly, are they calculating—what are they focusing on, and what does that suggest about the type of war they plan to fight? What is the interplay between mathematical models, complex algorithms, and human judgment in actual decision-making? How much trust do PLA leaders place in mathematical calculations and algorithmic assessment in their decision-making?

The Primacy of Process: It's not the Destination, It's the Journey

On one level, the most consistent theme across the body of literature is the focus on optimization: maximizing desired operational outcomes while minimizing undesired outcomes. On a deeper level, the predominant theme is the pursuit of ever more powerful suites of mathematical processes, in pursuit of the apparent conviction that all problems can eventually be made to yield to a mathematical process.

The body of research has passed through at least three phases of development, each linked to a higher level of operational complexity, and continues to evolve today. In the early 2000s, optimization work focused mainly on applying individual methodologies to individual platforms, for example, for optimizing efficiency in using torpedoes, sea mines, or maritime drones.

The second phase, around the 2010s, focused on a higher level of operational complexity but was still limited to single domains of warfighting or single military services executing discrete types of operations. Examples of research focus at this level include air-to-ground attack operations and ballistic missile target allocation processes. This level of research was characterized by efforts to layer and sequence methodologies that were never designed to be used in tandem. In this way, the researchers sought to retain the strengths and compensate for weaknesses inherent in the individual methodologies developed during the first phase of research.

In one example, researchers first generated a series of options that optimized mission outcomes according to the intentions and preferences of a human commander. This provided a list of options optimized according to a single individual representing a single mission requirement. They then analyzed these options against a different methodology designed to weight the strengths and weaknesses of each when compared to the strengths and weaknesses of theoretical opponents, which provided a list of options from the perspective of multiple individuals and multiple, conflicting mission requirements. Finally, they analyzed this set of options against yet another methodology designed to compare the mathematical differences between the prioritized list of desired outcomes against the actual situation at the start of the operation, essentially calculating how much change the operation would need to create in each aspect of the mission in order to reach a point at which it could qualify as mathematically successful.[10]

By the early 2020s, researchers were experimenting with layering and sequencing methodologies for higher-level complex operations, such as maritime blockades or combined arms urban warfare. Joint warfighting at this level would require the type of single operation optimization described above to be synchronized and orchestrated with other operations going on around it, say to make up a major battle or a campaign.

At this level, they were also apparently just beginning to explore algorithmic ways to manage the dynamics of combat operations, such as changes in operational capacity due to resource expenditure. For example, one paper published in 2022 notes:

> At present, the contribution rate assessment of a given system is generally a static assessment, ignoring the interaction of [different types of] equipment as a systems operation. In actual combat, the battlefield environment is constantly changing, and weapons and equipment are lost at any time. At present, there is no assessment method that can combine dynamic and static contribution rates.[11]

Importantly, this evolutionary step began to see experimentation with more advanced algorithms, especially genetic algorithms, so named because they mimic the biological evolutionary process. Natural evolution takes place across a population of individuals, which, over generations, develops the most appropriate mutations for their environment. For combat operations, the methodologies first generate a set of optimized calculation outputs, the result of scores or hundreds of algorithm iterations balancing multiple options for dozens or hundreds of combat variables. This forms the "population" of optimized choices, selected because they are the "fittest" for the tasks at hand. As the genetic algorithm continues to iterate, the population then mutates in accordance with such factors as gains in combat effectiveness due to experience or loss of combat effectiveness due to attrition, growing through different mixes of capabilities and limitations applied to successive combat environment challenges, and generating successive generations of (theoretically) improved operational outcomes.[i]

This is very much the scientific method in application to complex military problems. This scientific application enhances confidence that the resulting insights are sound and reliable because the scientific method in general has shown itself to be sound and reliable. This belief is reinforced because the methods PLA researchers employ have generally been adopted and adapted from non-military fields, usually economics and social research, where they have demonstrated reliable performance for years before the military considered using them.[ii]

Theory or Practice: How Much of This is PLA Operational Reality?

Of course, it is important to note that the authors who generated this body of literature are students of process mathematics, engineers, programmers, and systems architects for whom a scientifically calculable approach to problem solving is a professional characteristic. There is nothing in the literature that speaks directly to the degree to which their work reflects PLA officer thinking in the operational world, for whom math may be a tool but not a way of life.

Although there is no way to tell from this body of work which specific processes are transitioning from the research to operational practice, there are some indirect indicators that suggest that this approach in general, and therefore the top-level insights explored here, are basically aligned with PLA operational reality.

The first is the consistency of recurring topics over time. The emphasis on complex calculations as the only rational, "scientific" means of generating military operations remains consistent over more than two decades. This suggests an enduring PLA institutional culture that values this approach.

A similar indicator comes from the functions of institutions generating the work. The literature stems from national- and service-level military institutions, as well as national

[i] Mutation also occurs because of deliberate random variations built into the algorithm. This is done to increase the level of realism in the algorithm outputs.
[ii] It is important to note, however, that PLA researchers recognize the fundamental differences between military decision making and decision making in other fields. Indeed, adapting non-military MDCA/MDCM for the complexities, speed, and peril of the military environment is one of the central considerations in the body of research.

institutions with interests that overlap with national security issues, that have a history of contributing to national security and military capabilities, and that generate doctrinal work that is later reflected in PLA operational posture. While there is certainly some degree of novel thought producing independent research, the general trend over time is for these institutions to produce work that responds to a demand signal from the operational PLA or that addresses challenges in PLA operations. This is especially the case for a topic that has received such consistent and evolving research focus across several top-level and service-level institutions, lasting more than two decades. This suggests that further developing the mathematical approach to managing warfare remains of interest to the highest levels of the operational PLA.

Next is the degree of consistency between the research and the core concepts in other doctrinal writings from similarly authoritative bodies. The themes that emerge from an analysis of this body of literature show a strong correlation with the principles of Effective Control, especially the element of War Control, that have been developing in PLA doctrinal writings for over two decades.[iii] These are most notably expressed in the 2001 and 2013 editions of the *Science of Military Strategy* (SMS) published by the Academy of Military Sciences (AMS), and the 2020 SMS edition published by the National Defense University. SMS documents are provide doctrinal guidance, not operational direction. Nevertheless, their purpose is to train PLA leaders in the practical application of operational doctrine, which in turn was developed to implement top-level CCP guidance on warfighting. In fact, the development of new doctrine is one of the principal missions of AMS, further indicating the conceptual coherence between the SMS and the doctrine guiding the operational PLA. The concepts underlying Effective Control and War Control reflect the same factors that run through the body of literature on operational optimization:

> The nature of warfare has changed: war has become more fast-paced, expanded across multiple mutually influencing domains, and become more high-tech. Although the wars China anticipates facing are controllable, limited-objective local wars, the requirements to control such wars have become more complex and challenging.[12]

Similarly, the response to these challenges as reflected in the body of literature also align directly with the doctrinal definition of War Control provided in the 2013 AMS SMS:

> War situation control [控制战局], sometimes called war control [控制战争], refers to activities during actual warfare "to adjust and control the war's goals, means, scales, tempos, time opportunities, and scope, and to strive to obtain a favorable war conclusion at a relatively small price.[13]

[iii] Research into mathematical means of operational optimization is closely related to the study of cybernetics, which is the science of the operation and stability of large, complex systems, such as militaries in operational environments. It is worth noting that the Chinese name for cybernetics translates literally to "control theory" (控制论), and that this word shares the same root as "Effective Control" (有效控制) and "War Control" 控制战争), suggesting that they are conceptually related.

The body of literature examined here is intended to do exactly these things. Taken together, this suggests a consistency between top-level guidance, operational doctrine, demand signal from operational commanders, and academic research that has remained aligned and essentially unchanged for over 20 years.

Another indicator is the degree to which the core concepts in the academic writing reflect the larger institutional culture that shapes the management of other national instruments of power. A complex systems engineering approach to top-level governance has been a characteristic of PRC national leadership thinking since Deng Xiaoping. Chairman Xi Jinping has not only embraced this approach but has made it a central theme of his administration:

> Xi has repeatedly demanded Chinese Communist Party (CCP) cadres to use "systems science, systems thinking, and systems approaches" to examine and solve problems, and upholding a "systems mindset" was identified as one of five fundamental principles to guide economic and social governance during the 14th Five-Year Plan (FYP) period and beyond.[14]

Xi has explicitly included military capability development within this cybernetic framework. In November 2013, having been in office about one year, Chairman Xi gave a speech to the 3rd Plenum of the 18th Congress of the CCP in which he laid out the military reforms his administration would pursue, and framed the overall undertaking as a "complex systems engineering project."[15] One week later, then Senior Vice Chairman of the Central Military Commission, Gen. Xu Qiliang, reinforced that approach and reemphasized its applicability specifically to military reform.[16]

Tensions Between Human Judgement and Algorithmic War Management

This highlights a critical tension between the enduring, top-down emphasis on scientifically objective methods for managing highly complex systems with high consequences of success or failure; and on the professional skills of the cadre of PLA officers and the demands of warfare on human commanders.

On one hand, the PLA is proud of its ability to draw on the insights of Chinese warfighting experience ranging from Sun Tzu to Mao Zedong. Top-level PLA education institutes train officers in the insights from *The Art of War* written over 2,000 years ago; to the "Three Campaigns," September 1948-January 1949, that opened the door to the CCP seizing control of China. The common thread through this material is the importance of military leaders who are able to correctly read the moment, correctly interpret the underlying dynamics, and make the insightful choices that will ultimately carry the day. This is the essence of what PRC leaders believe is a uniquely Chinese contribution to world military wisdom, all of it springing from human insight, none of it derived from an algorithm.

On the other hand, as of the mid-2020s, PLA research on mathematical operational optimization methodologies appears to be evolving to the point that the balance between art and science in military operations, essentially the balance between Sun Tzu's classic *Art of War* and the PLA's *Science of Military Strategy*, appears to be shifting to the extreme "science" end of the spectrum. In this era of increasingly complex, informatized, and intelligentized forms of warfare, any room for the art of war appears increasingly limited to the art of algorithm design.

In fact, several of the research papers identify human subjective judgment as *the principal* impediment to operations optimization:

> In traditional military decision-making activities, decision-makers and analysts are accustomed to looking for appropriate solutions to difficulties from past experience and conventions, hoping to find a similar "template" from events that have already occurred. With the continuous development of science and technology and the continuous progress of the times, *subjective empiricism can no longer meet the needs of military decision-making activities under modern conditions*.[17] (Emphasis added)

Another research team observes:

> The indicators are overly reliant on expert experience and knowledge. This manifests itself in two ways: first, the quantification of qualitative indicators relies on expert experience, and second, the weights of the constructed indicators are determined subjectively by experts. This leads to inaccurate evaluation results.[18]

From this perspective, the principal challenge to mathematical optimization is not the complexity of the operation, but rather the inconsistency and fallibility of human judgment. This is a common theme across the body of literature. Most of the papers state that at least one purpose, if not the main purpose, is to minimize the role of human subjectivity in planning operations; or they assess the level of success of their research by the degree to which it minimizes human subjectivity; or both.

This suggests a trend in the thinking increasingly evolving towards what would be an essentially deterministic approach to military planning. At one level, the objective of optimization is the best possible balance of capabilities and challenges. On another level, the objective is the pursuit of a sort of mathematical purity that can endow military operations planners with an exceptional power, the indisputable power of science. The underlying approach essentially says, "If you want to get the operation right, you first need to get the math right."This approach then evolves into the idea that "If you get the math right, you're going to get the operation right." In theory, operational confidence should stem from the correct mathematical process.

This is consistent with a larger PRC institutional culture that prioritizes process. This tendency is apparent in most state-level planning and policy making, where the emphasis is on *how* decisions are generated, rather than on *what* the decisions are. This is not to say that there is a blind faith in the outcomes of the process. The system includes steps for review, vetting, and adjustment. Rather, it reflects the view that if one builds a top-quality decision-making process, the decision options it generates cannot help but be the best possible options.

The main difference is that decisions for execution in military operations have more potential for immediate consequence before they can be tested, adjusted, and reapplied. A deterministic approach that may work well for a non-military problem, for example in urban planning or financial management policies, where there is more room for trial-and-error, is a more fraught approach when applied to military decision-making, where defeat could arrive before the option to review and adjust previous decisions.

Does this suggest that one approach towards resolving what Xi Jinping has identified as the critical shortcomings of PLA officer professional decision-making skills, what he calls "The Five Cannots," is to mathematize, intelligentize, and automate the military decision-making process?[iv]

Almost certainly not. Rather, PLA leaders are clear that human decision-making remains critical to effective military operations. According to Lt. Gen. Liu Guozhi, Director of the Central Military Commission Science and Technology Commission, for example, "The combination of artificial intelligence and human intelligence can achieve the optimum, and human-machine hybrid intelligence will be the highest form of future intelligence."[19]

However, just where the balance should be between a powerfully automated process and a human commander exercising subjective judgement remains far from settled. Two views published fewer than 18 months apart (February 2025 and June 2026) make this point. On one hand, researchers propose a model for a "virtual commander" to fill the "essential 'human-not-in-the-loop' element missing in joint warfighting simulation models." This "virtual commander" has the ability to assess enemy and friendly situations and the battlefield environment and can exercise the three core functions of a commander, namely situational awareness, operational decision-making, and operational control.[20]

Another group of researchers reflects the view that the role of higher-level optimization technologies, in this case using artificial intelligence, will be as a tool in the service of the human commander, not as a substitute for him:

> As modern warfare becomes increasingly information-intensive, fast-paced, and complex in its force composition, command and control systems face significant challenges—such as difficulties in perception and cognition, tight timeframes for decision-making and response, and a scarcity of domain-specific knowledge. Traditional decision-making methods relying solely on the human brain struggle to meet the demands of modern warfare; *there is an urgent need to augment the commander's intellect with intelligent machine-based systems to enhance the scientific rigor and efficiency of decision-making*.[21] (Emphasis added)

[iv] Xi Jinping's "Five Cannots" are that PLA officers "cannot judge the situation, understand the intentions of their superiors, make combat decisions, deploy troops, or handle emergencies." Wang Xueping, "Work Hard to Crack the Problem of the "Five Cannots." (着力破解指挥员"五个不会"问题), *PLA Daily*, 18 June 2019, Reproduced in Qiushi Theory https://www.qstheory.cn/defense/2019-06/18/c_1124638783.htm

Clearly, “PLA scholars and strategists are continuing to debate the appropriate relationship between human and machine intelligence on the battlefield:”[22]

> Whereas some scholars have warned against autonomous decisionmaking, other researchers have differentiated between the eventual necessity for automation or “intelligentization” of command decision-making at the tactical level of warfare, the importance of the delegation of command authorities in campaigns, and the imperative of human control in strategic decision-making, in which AI can take on a supporting function.[23]

Finally, almost all of the processes described in the optimization research incorporate a prioritization and weighting stage early in the process. In this stage, the constituent elements of any given operation receive numerical values based on their criticality to the overall problem. In all cases, this step requires the subjective judgment of a human commander who has the authority and responsibility to set priorities, and of human subject matter experts, who have the professional experience to assess how much each individual element contributes to the overall operation.

The common baseline underlying this tension is the need for retaining human decision making to oversee the process or make choices about operational execution, and the impossibility of removing humans from the process because only humans can make the necessary prioritization decisions or assign values to otherwise unquantifiable variables prior to calculation. The disagreement is about where the balancing point should be between automation and human decision-making. In fact, there is probably no single answer to this problem. The balancing point will vary depending on level of complexity, the nature of the problem to be calculated, and the power of the mathematical, algorithmic, or artificial intelligence tools on hand, all factors which are constantly evolving.

No degree of emphasis on scientific rationality in decision-making will eliminate the need for subjective human judgments, but the nature of the problems that modern warfare presents will continue to drive the balancing point between automation and humanity into new areas of research.

Please note that the quote above about the debate over autonomous decision-making suggests a hierarchical approach to managing these tensions and setting the balancing point. It appears likely that the human-automation balancing point in the operational PLA follows a similar, hierarchical approach, as the next section will explore.

Aligning Operational Optimization Processes with Operational and Human Realities

A review of the PRC research literature suggests some ways in which the tensions between human decision making and calculated optimization may be resolved. The literature on mathematical operations optimization covers a deep range of applications. Although there is no such explicit distinction in the body of literature, the research generally falls into three groups, differentiated by the rough levels of complexity of the various military capabilities or the operations they examine. This is displayed in the graphic below. Group 1 examines the less complex problems presented when optimizing individual systems. Group 2 then moves to research focused on optimizing warfighting problems employing a single military service or within a single warfighting domain. Group 3 culminates with the more complex algorithmic structures designed to manage higher levels of complex operations involving multiple military services across multiple domains.[v]

The body of literature also includes some research focused specifically on computer simulation and modeling for developing and testing the next iterations of improved calculation methods and algorithms, without necessarily focusing directly on a specific type of operation.[24] This is a much smaller body of research, but stands apart from the other, more specifically focused research, and so constitutes a fourth group in the conceptual organization shown below. Because this research is not aimed directly at supporting PLA operations optimization, but is designed to support further research, it is not further examined in this paper.

[v] Although the literature does not distinguish or group research according to its different levels of complexity, PLA researchers do recognize that a similar consideration would offer some important analytic advantages. For example, writing in 2022, authors from the PLA Rocket Force noted:

> "System" refers to the whole which is composed of different systems in a certain range or the same kind of things according to a certain order and internal connection. In a broad sense, all weapons and equipment can be a system; in a narrow sense, individual weapons and equipment can also be a system. For different systems, the index complexity is different, the system data is large and complex, and thus there is uncertainty resulting in the evaluation results having a certain one-sidedness and low credibility.

See: Zhang Xiaoyu, et al, "A Review of the Mathematical Evaluation Model of the Contribution Rate of Weapon Equipment Systems," PLA Rocket Force Engineering University College of Missile Engineering, Xian, Section 5.1., writing in the *Academic Journal of Computing and Information Science*, 2022. https://francis-press.com/papers/6972

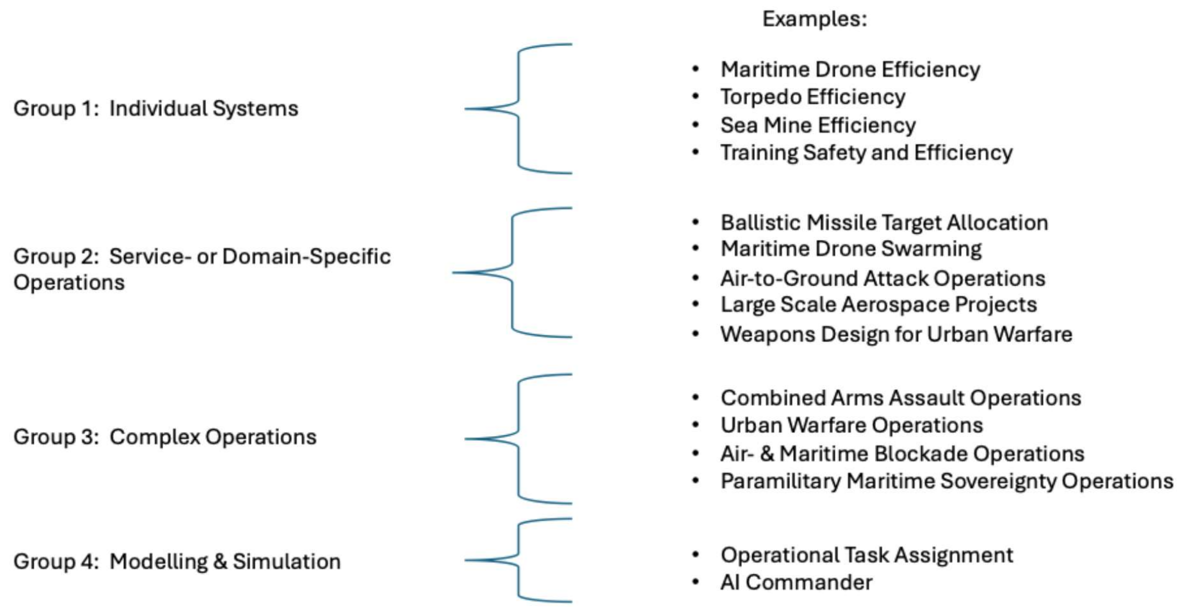


Figure 1: Grouping Optimization Problems by Level of Complexity

Although the body of research makes no explicit distinction between levels, one patent application for an "operational task planning process and system based on artificial intelligence" states that "Combat mission planning is divided into four levels: weapon platform level, tactical level, campaign level and strategic level."[25] Assuming this is an accurate statement, it suggests that the grouping of tasks apparent in the body of research do basically mirror PLA operational planning distinctions.

Optimization research on Group 1 systems generally addresses the question of how to maximize mission readiness, availability, and operational efficiency of discrete systems. This research does not generally include considerations for operating different types of systems or different functions in tandem, so the optimization problems tend to be straightforward and discrete.

Below is a typical example of one step in an optimization research project at this level. Here, calculations of the relative weights of the various operational capabilities and parameters of maritime drones help frame the commander's decision-making process for optimizing mission availability for this type of platform: [26]

<u>Evaluation of the combat effectiveness of maritime drones</u>: Weight of Second & Third Level Factor Dimensionless Values of each Third Level Factor In Each State

Second Level Factor	Weight	Third Level Factor	Weight	Third Level Functional Status Dimensionless Values						
				No Malfunction	System 5 Malfunction	System 6 Malfunction	System 7 Malfunction	System 5&6 Malfunction	System 5&7 Malfunction	System 6&7 Malfunction
Mobility	0. 099 8	Takeoff/Landing	0. 072 6	0. 833 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3
		Climb Rate	0. 170 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3	0. 833 3
		Patrol Altitude	0. 106 8	0. 9	0. 9	0. 9	0. 9	0. 9	0. 9	0. 9
		Patrol Speed	0. 287 7	0. 925 0	0. 925 0	0. 925 0	0. 9250	0. 925 0	0. 925 0	0. 925 0
		Endurance	0. 227 8	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7
		Max. Range	0. 134 8	0. 857 1	0. 857 1	0. 857 1	0. 857 1	0. 857 1	0. 857 1	0. 857 1
Defenses	0. 051 9	Stealth Capabilities	0. 333 4	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7
		Damage Survival Capabilities	0. 666 6	0. 8	0. 8	0. 8	0. 8	0. 8	0. 8	0. 8
Reconnaissance & Surveillance	0. 245 0	R&S Payload Type	0. 072 1	0. 9	0. 7	0. 7	0. 7	0. 65	0. 65	0. 65
		Detection Range	0. 103 8	0. 777 8	0. 622 2	0. 622 2	0. 622 2	0. 544 5	0. 544 5	0. 544 5
		Detection Resolution	0. 233 6	0. 444 4	0. 444 4	0. 444 4	0. 444 4	0. 444 4	0. 444 4	0. 444 4
		Realtime Transmission Rate	0. 130 4	0. 8	0. 8	0. 8	0. 8	0. 8	0. 8	0. 8
		Line of Sight Tracking Link	0. 235 9	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7
		Target Detectability	0. 224 2	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7
On-Site Evidence Collection	0. 196 8	Resolution	0. 163 5	0. 5	0	0. 5	0. 5	0	0	0. 5
		Infrared Recognition Range	0. 296 9	0. 6	0	0. 6	0. 6	0	0	0. 6
		Visible Light Recognition Range	0. 539 6	0. 666 7	0	0. 666 7	0. 666 7	0	0	0. 666 7
Calling & Warning Capability	. 123 5	Hailing Range	1	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7	0. 666 7
Weapons Engagement Capability	0. 046 1	Range	0. 195 8	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7
		Accuracy	0. 493 4	0. 5	0. 5	0. 5	0. 5	0. 5	0. 5	0. 5
		Target Tracking Capability	0. 310 8	0. 75	0. 75	0. 75	0. 75	0. 75	0. 75	0. 75
Electronic Countermeasure Capability	0. 097 2	Communications	0. 296 9	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7
		Navigation	0. 539 6	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7	0. 7
		Electrical Interference	0. 163 5	0. 6	0. 6	0. 6	0. 6	0. 6	0. 6	0. 6
Communications Capability	0. 139 7	Network Coverage	0. 527 9	0. 96	0. 96	0. 96	0. 96	0. 96	0. 96	0. 96
		Information Transmission Rate	0. 332 5	0. 85	0. 85	0. 85	0. 85	0. 85	0. 85	0. 85
		Comms Bandwidth	0. 139 6	0. 8	0. 8	0. 8	0. 8	0. 8	0. 8	0. 8

Figure 2: Example of a Typical Group 1 Optimization Step

Human oversight at this level is necessary, but minimal. In fact, at this level the human commander may discharge his role entirely before the calculations begin by setting certain acceptable parameters for drone functionality and establishing standing maintenance processes. The remaining human role would then be at the maintenance and operator levels to ensure that the above parameters and processes, on balance, conform to the commander's intent prior to operation.

In Group 2 systems, operational optimization calculations tend to focus on efficiency of combat resource allocation for individual types of operations (air-ground support, for example) and optimizing the likelihood that the operation will achieve the desired outcomes. At this level, the complexity of the operation is higher because multiple systems must function in tandem, and because there is an adversary involved who will have agency in how the operation unfolds.

However, the importance of optimizing these operations tends to be limited to their contribution to the overall mission. They will impact, but are unlikely to decide, the success or failure of the larger mission.

The example below shows an early stage of a decision-making process for a PLA Rocket Force commander to make target allocation decisions that optimize the missile inventory he has on hand for any given operation:[27]

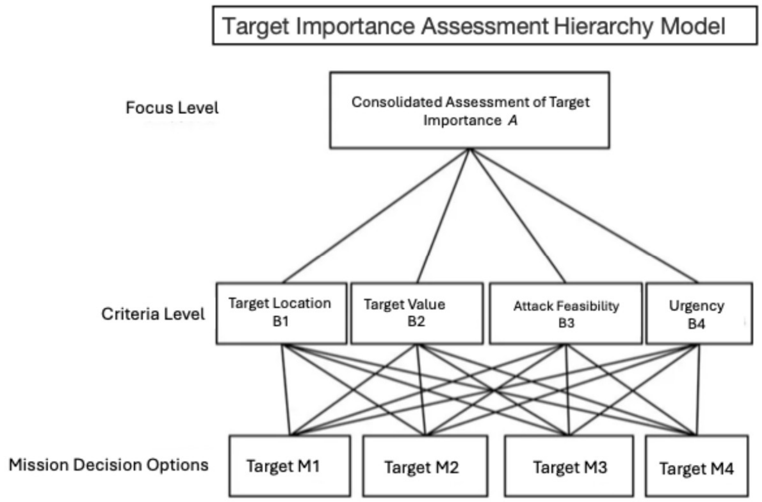


Figure 3: Example of a Typical Group 2 Optimization Step

At this level, the function that falls to the human element would be the need for the commander's intent to set the desired range of outcomes. For example, at this stage in the execution of this methodology, the human decision maker would be called on to make decisions about the target value and the urgency of engaging the target. Although each of the four target criteria are dynamic and contextual (for instance, location and attack feasibility will also change over time), the most fundamental decisions in effective weapons allocation decisions center on the target value and the urgency to attack. These must be dictated by the higher commander's intent and therefore require human assessment and direction.

To continue this example, one of the next steps in this missile-target allocation optimization process calls for a consideration of the political and economic value of the target (in the figure below these are criteria 4 and 6, respectively), in addition to the military value (criterion 5):

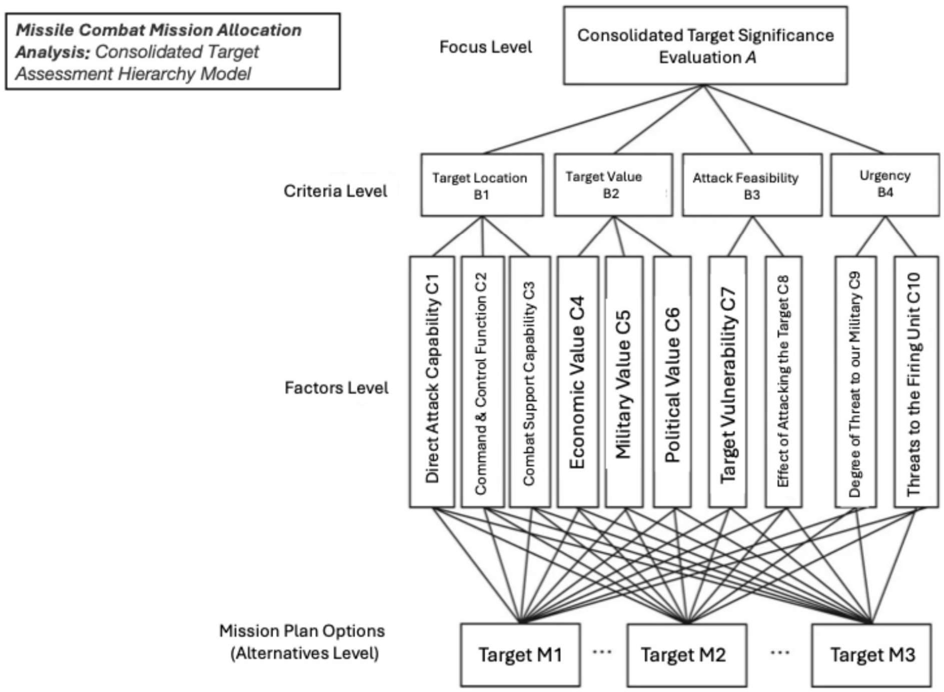
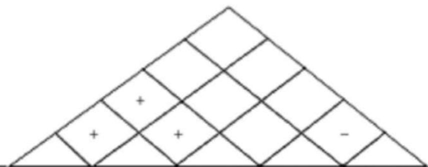


Figure 4: Example of a Human Decision Point in a Typical Group 2 Optimization Step

As this optimization process moves through its evolution, the human requirements might be for the operational staff to confirm that the output of the optimization process conforms to the commander's intent, and for the commander to choose between (or reject) the various courses of action that the optimization process has generated. These choices rest, among other criteria, on the number and type of missiles available in the inventories of the various firing batteries available to the commander at that stage in the conflict, and his assessment of what combat demand is likely to be placed on his remaining inventory in the battles to come. While these can be calculated mathematically, the effective use of remaining inventory can only be decided by the intent of the superior commander, another essential point of human judgment.

With an emphasis on optimizing operations plans at the battle or campaign level, in which all of the systems at Groups 1 and 2 must be effectively orchestrated in a dynamic and interactive environment, Group 3 represents the highest levels of complexity and the highest level of consequence that the body of research addresses. Research on these optimization problems seeks to tackle military operations ranging from discrete battles in urban warfare environments to paramilitary maritime operations designed to support national policy objectives, to full-scale island blockade operations using air and maritime assets.

The example below is from an optimization methodology designed for "ground forces combined arms unit positional attack combat planning." This is a suitability matrix generated by sequencing two different optimization methodologies, each involving a five-step calculation process, which have generated four combat plans evaluated against a total of twenty assessment criteria:[28]



Requirement	Weight	Operational Purpose	Feasibility	Combat Effectiveness	Combat Risk	Adaptability	Plan 1	Plan 2	Plan 3	Plan 4
Alignment with Superior Intent	0.27	9	7	3	3	1	7.727 6	8.091 8	7.778 3	7.904 7
Unit Level Effectiveness	0.51	7	5	7	5	7	7.767 3	7.669 8	7.900 1	7.774 3
Alignment To Enemy	0.14	5	5	7	5	5	7.701	7.761 9	7.902 2	7.780 9
Battlefield Environment Suitability	0.08	1	3	3	7	3	7.769 2	8.077 4	7.821	7.562 6
	Plan 1	8	7	8.2	8	7				
	Plan 2	9	8	6.9	9	5				
	Plan 3	7.2	7.4	9	7.5	8.2				
	Plan 4	8.8	6.7	8.5	6.8	6.6				

Operational Plan Evaluation House-of-Quality (HOQ) Values

Figure 5: Example of a Typical Group 3 Optimization Step

The researchers in this work specify that the intent of the process is for the human commander to decide from the operations plans developed through the optimization calculations. But the decision is not his alone. Note, for example, the criteria “Alignment with superior intent,” and “Operational purpose.” These can only be set through a decision by another, higher-level human commander. For complex operations at this level, the higher-level intent may be to achieve a rapid and overwhelming victory, or to prepare for a subsequent operation, or to relieve pressure on an operation taking place elsewhere with a different objective, or to execute a deception or feint, or any number of wartime objectives. These decisions can only be made by a human being. The optimization processes in this research are not dictates, but option-generating calculation machines intended to be responsive to whatever the commander’s intent in a specific and dynamic combat context may be.

Choices between military, economic, or political impact; what role deception should play; or how to sequence operations that build into sustained campaigns are not the only impediments to removing the human from the operational optimization loop. Because the research at these higher (Group 3) levels is attempting to manage challenges posed by human opponents at high levels of military and political decision making they must also include assessments of the opponent’s human perceptions, motives, interpretations, calculations, and cognition. Adding to the complexity, these assessments must be repeatedly updated as the dynamic of the conflict changes the situation on the ground and in the minds of the people contending on both sides.

For example, the matrix below provides an analysis of comparative "strengths, weaknesses, opportunities and threats" (SWOT) of a calculation process designed to optimize comparative military and paramilitary postures between three countries in a contest over maritime sovereignty in the South China Sea:[29]

SWOT Combined Strategy Matrix

	Strengths (S)	Weaknesses (W)
	S1: Island H is under the actual control of the Country A coast guard S2: Country A has a strong coast guard force deployment at Island H S3: Country A's cost guard has an overwhelming force advantage over Country F	W1: Ship maneuverability and combat power are less than those of Country B's coast guard patrol ships W2: Air power is relatively weak W3: Ship resupply and combat power replenishment periods are long, support at sea is difficult
Opportunities (O) O1: Country B has limited interests in interfering over Island H O2: Island H is well suited for storm and typhoon avoidance O3: Country A has advantageous maritime power policies	SO Strategic Course of Action: Country A's coast guard strengthens control measures at Island H, sustaining its deployed forces advantage to remain on guard at the island.	WO Strategic Course of Action: Take advantage of Country A's policy of maritime strengthening, rapidly develop coast guard surface and air force capacity.
Threats (T) T1: Country F's ceaseless petty, futile efforts to return to Island H T2: Lack of crisis control mechanisms between the coast guards of Countries A & B T3: Third parties with island territory disputes with Country A will be watching like tigers	ST Strategic Course of Action: Strengthen the on-guard posture at Island H and surrounding contested maritime features, strictly prevent Country F's bad intentions; at the same time avoid any potential direct conflict with the Country B's coast guard.	WT Strategic Course of Action: Strengthen surface vessel performance and build air capacity, shorten sea rotation periods; at the same time cautiously manage disputes, avoid conflict with Country B or other countries.

Figure 6: Example of Human Decision Points in a Typical Group 3 Optimization Step

Note that the criteria include assessments of political motivation, policy alignment, national interests, and opportunity-seeking by outside parties. None of these human criteria lend themselves to the effective quantification necessary for complex mathematical processes. These elements remain the domain of human decision-makers.

The Certainty of Uncertainty

While optimization is the explicit focus of the research, it is only half of the story. The purpose of every military operation turns not only on cost-benefit calculations, which is the realm of optimization; but also on risk-gain calculations, which is the realm of uncertainty.

In defining operational risk, one research team writes that:

> [Risk] is a product of the uncertain conditions of military operations and refers to the possibility and consequence of military forces being unable to achieve mission objectives or suffering significant losses during the course of operations.[30]

Thus, the first aspect of dealing with uncertainty is to recognize that it is an inescapable byproduct of any military operation. Therefore, every effort to calculate an optimized military operation must include math that accounts for the certainty of uncertainty.

Optimization is about balancing tradeoffs. Balancing requires bounding and measuring: defining the principal components of a problem and comparing their relative weights. If one can thoughtfully draw boundaries around the unknowns, they can then be categorized, placed within the larger context, and their influence can be defined in terms of "coin toss"—maybe/maybe not—outcomes.

Accordingly, the general approach in the literature is to consider uncertainty as a function of risk, meaning the impact to the mission should an area of *potential* setback become an *actual* setback. From a process standpoint, this means bounding uncertainty and then calculating around it: impose various limitations on the scope of potential uncertainties and then calculate ways to mitigate the impact on the operation should a risk event occur, and an uncertain possibility becomes an actual event.

Consider the holographic risk scenario model associated with an air and maritime blockade operation shown below:[31]

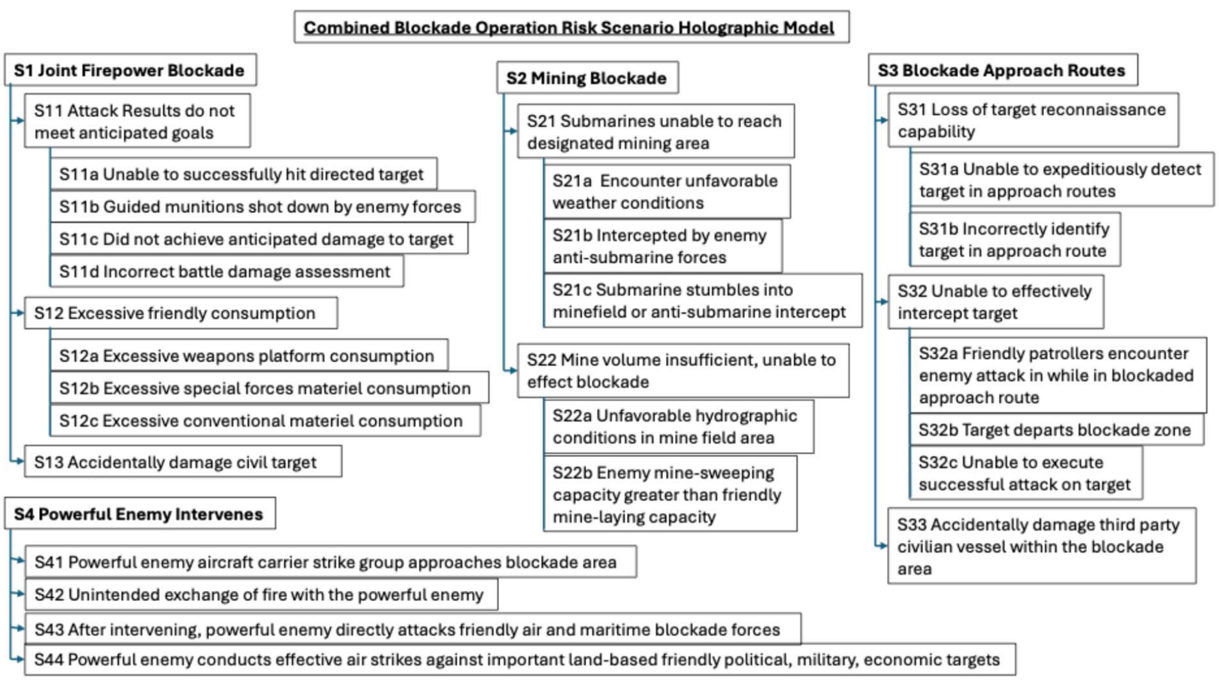


Figure 7: Risk Scenario Holographic Model

This model is actually a structured categorization of the various types and levels of uncertainty involved in an air and maritime blockade operation. Each of the factors in this model is a "what if" consideration: this is not only a list of things that might go wrong, but is the prelude to methodically answering the question "What happens *if* they go wrong?" The work goes on to weight and matrix each of these risks by likelihood and consequence of occurrence. This is conceptually similar to the U.S. approach,[32] but is significantly more invested in the details of mathematically bounding and calculating around the uncertainty. These authors build the bulk of their research around math that bounds and calculates the impact to the overall mission should one or several uncertain risk events become a reality. They conclude by introducing a Bayesian-based algorithm for correcting the risk scenario attribute values":

$$p(\bar{x} \mid \bar{e}) = \frac{p(\bar{e} \mid \bar{x})p(\bar{x})}{p(\bar{e})} = \frac{[1 - p(e \mid \bar{x})]p(\bar{x})}{[1 - p(e \mid \bar{x})]p(\bar{x}) + [1 - p(e \mid x)]p(x)}$$

Figure 8: Risk Calculation Formula Concluding a Comprehensive Risk Optimization Process

Where the variables represent the operations elements successfully completed and operations elements that failed because the potential for risk eventuated; and individual missions successfully completed and individual missions that failed because of risk eventuation; concluding with the statement, "Thus, it is easy to calculate the likelihood that the failure of any given operational link will lead to failure of the overall (entire) mission."[33]

The literature systematically imposes similar analytic structure and rigor to bound and calculate the effect of uncertainty. The calculation emphasis starts with the known factors: an actor knows what things they want the most of, what they want the least of, and how to calculate what the tradeoffs are. This offers a more certain approach to dealing with uncertainty: they define it where they can, they categorize it where it remains undefinable, then they calculate options for both defined and categorized uncertainties.

This approach to risk management is explicitly designed to offer as many feasible options as possible to circumvent risk for instances when unforeseen and undefined uncertainty might appear. The concept behind this appears to be, "the more variables we can build into the system, the more calculations we can generate to flex around impediments to the operation."

Implications for Deterrence

Deterrence is part of a larger field of shaping the thinking and behavior of an opponent. All such activities center on perception and uncertainty. Perception forms an actor's understanding of the operating environment; uncertainty describes the actor's degree of confidence that their understanding is or is not complete, accurate, and reliable.

Across the body of literature, the emphasis on optimization, augmenting (if not attempting to override) human subjectivity, and the treatment of uncertainty make it clear that attempts to shape PLA military operational thinking and behavior will have effect primarily to the extent to which they can shape PLA mathematical calculations.[vi] Deterrent actions such as efforts to increase PLA uncertainty will first enter PLA consideration as quantified and weighted variables. These will have been analyzed for their probable veracity before taking their place in the larger sets of variables representing all aspects of the pending operation, friendly and enemy.

The influence that perceptions and uncertainty exert on the human decision maker are thus tempered—bounded, quantified, and mitigated through objective, "scientific" calculation. The influence of the deterrent action will become apparent only through its ability to influence the output of the optimizing algorithm. In this way, the PLA's mathematical processes move perception and uncertainty from primarily influencing subjective human cognizance to primarily influencing the balance of one or several complex mathematical processes. This essentially removes the element of perception from the operational deterrence process.

Consider, for example, U.S. or allied actions intended to shape PLA thinking about executing an operation as part of a Joint Firepower Strike, such as actions intended to deter PLA missile strikes on a given target. These might be efforts to harden the target, to enhance antimissile defenses, to complicate targeting, or any other measure. For this example, the specific action is less important than how the fact of that action would likely play out in a PLA Rocket Force firing unit command decision-making process.

Returning to our optimization methodology for ballistic missile target allocation, cited earlier:[34]

[vi] Note that there is a difference between strategic deterrence, which involves senior leader decisions about *whether* to use force; and operational deterrence, described here, which involves military commanders' decisions on *how* to use force. The basic concepts of deterrence remain the same for both, but the objectives are different. In the case of operational deterrence, the objective is to shape the cognitive dynamics of the conflict. This is different in scope and scale than trying to shape senior national leaders' political objectives for the conflict, including whether and when to end the conflict.

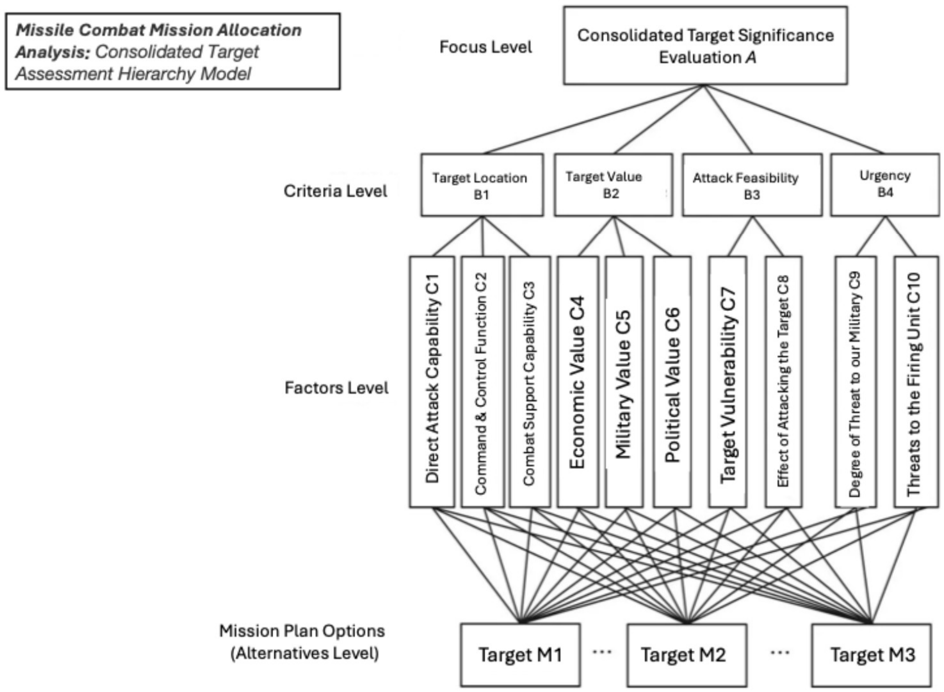


Figure 9: Attack Criteria Characterizations in a Model Group 2 Optimization Process

In this example, the adversary deterrent actions become variables falling under Criteria B3: Attack Feasibility, Factor C7: Target Vulnerability, and/or Factor C8: Effectiveness of Attacking the Target. The Rocket Force unit staff would include intelligence and reconnaissance information about the deterrent action in the calculations that generate numerical values for these two criteria.

The adversary deterrent actions would then be quantified and weighted according to an analytic hierarchy process and then calculated through a genetic algorithm designed to optimize outcomes: to maximize beneficial outcomes and minimize adverse outcomes.[vii] The output values are then entered into an overall decision support matrix. In this example, the comprehensive assessment for the target—one of several under consideration—is presented as a 0-1 rating for each of the four combat criteria:

- Target Location: 0.3950
- Target Value: 0.0473
- Attack Feasibility: 0.3950
- Attack Urgency: 0.1626

[vii] Analytic Hierarchy Process (AHP) is one of the most widely used MDCA/MDCM processes in the world today. It is part of most PLA operational optimization methodologies, typically employed as one of the initial steps in a complex process. It most often serves to methodically break down a complex decision into its constituent elements and factors, and then to prioritize factors according to the commander's preferences.

In this approach, the deterrent value of the action meant to shape the PLA commander's decision about striking the target ends up as a part of a numerical value embedded in one factor (Attack Feasibility) of four total factors. In this example, the deterrent activity accounts for 10 percent of the commander's consideration of the overall operation (0.3950 equals roughly 40 percent. This is one of four decision criteria, so 25 percent of the decision. 40% of 25% = 10%). Note that there is no room for perception in the algorithm. Effect is achieved through calculated variable inputs only. This is not to say that perception is an entirely nondiagnostic element in operational deterrence. However, in this approach, any influence that perceptions might have must occur earlier in the process, namely in the quantification and weighting phases—which are still subject to subjective human judgment—which precede compiling the calculations and populating the algorithm for the human commander's consideration.

This management of perception and uncertainty cannot eliminate the effect of adversary deterrence efforts, but it can have a mitigating effect on how impactful they are in the PLA operational planning process. This may be a deliberate design feature of the system. One of the principal purposes of this body of research is to minimize points of failure and to maximize PRC ability to flex around failure. "Game changer" deterrent effects are still possible, but the process makes them more challenging because they would need to affect many factors in the calculus, across multiple systems, domains, and complex operations. Again, the PRC is designing its approach to operations optimization in part specifically to minimize the possibility of such events, whether they are precipitated by adversary intent or are unintended effects of the fog and friction of war.

Options vs Optimization: Advantages and Disadvantages

The body of research is incredibly complex and becoming more so. It represents an ongoing effort to capture, quantify, and calculate *all* combat-relevant variables, spread across all levels, services, types of operation, and the full scope of modern warfare. This complexity offers some advantages, at least in theory.

First, more variables, and the growing number of methods for combining and calculating them, offer more ways to multiply strengths and mitigate weaknesses. This offers greater flexibility in how to combine systems to work around the challenges an adversary might offer.

In designing ever more new and improved ways to optimize performance, the research is also systematically developing methods to minimize single points of failure, and to recognize, define, and mitigate weaknesses in their own systems. The nature of warfare dictates that no system can eliminate the potential for failure, of course, but they are striving to get as close as they can.

Also, several aspects of the research recognize the important role that political, economic, and societal considerations play in warfare. Although there are almost no efforts to quantify and calculate those factors into military operational plans, this does recognize that military activity serves desired political outcomes. In so doing, it recognizes that there are other ways to define military success beyond the strictly operational realm, adding yet more dimensions of flexibility to this approach.

But there are distinct disadvantages as well. In particular, the level of complexity requires data and processing capacity that threatens to impose restrictions on the scope and scale of operations. The mathematical representations and algorithmic processes essentially function as a machine designed to produce an enhanced likelihood of success. All machines need raw material to generate output. The raw material in this case is data, large amounts of timely and accurate data. The higher the level of operation, the greater the volume of data needed. The data must also be processed before it can be used. In most cases, it must be quantified and weighted before it can be fed into the optimization methodologies, which then support the optimization algorithms. For sustained operations, these large data sets need to be constantly refreshed with information reflecting the dynamic state of the operational environment, which changes constantly under combat conditions.

Because algorithms require time to run, there is an additional inversely proportional effect in that the more complex the operational environment to be calculated, the more likely a percentage of the variables will be represented by data that is no longer accurate by the time the calculations are complete. The trade-off is between the level of operational command (higher levels equal greater complexity, requiring more data and more time) and the operational relevance of the calculated insights (higher-level operations will have less time before the calculated insights begin to lose viability; lower-level operations may have a longer period of viability, but are less impactful in achieving the overarching political objectives).

Therefore, the higher the level of operational command, the greater the limitations on the scope of optimized operational plans the machine can generate (because the size of the required data sets is so great and the power of the algorithms is limited), and the shorter the period of operational reliability (because the validity of the data is perishable, and different sets of data will reach their shelf lives at different times during the operation).

Options vs Optimization: A Short-Sharp Tradeoff?

Considering the body of literature and the insights it yields, it is difficult to escape the impression that this approach to managing warfare may offer greater operational impact, but across a limited operational scope and duration. Logically, this trade-off would favor a short, sharp war rather than an extended conflict.

Efforts to maximize calculated optimality generate a trade-off between operational effectiveness (how likely it is that the operation will achieve the desired objectives) and operational viability (how long the plan is likely to remain realistically executable). Each step up in level of complexity carries with it a commensurate, and in some cases, exponential, increase in the number of variables involved in the calculations, the volume of data needed (and the number of sensors or other sources from which the data is obtained), and the number of linkages between variables.

At lower levels of complexity (Group 1 systems) the impact of this trade-off could be negligible: optimized means of employing a single weapons system, for instance, may remain viable for extended periods, and remain effective under a wide range of circumstances. At higher levels of complexity (Group 3 systems) the impact of this tradeoff could be decisive: optimized plans for executing a complex, joint operation may only be viable for a relatively brief window of time, depending on the larger conflict dynamics; and may be effective only within a specific set of combat circumstances.

The PLA's rapid military development includes deep, redundant, and overlapping sensor and information networks, as well as a growing effort to integrate computers, information fusion, and now AI, into combat decision support systems. These are in large part designed to provide the algorithmic optimization machine with the rich and timely processed data streams it needs to function at scale and at speed. Ultimately, complex and effective sensor networks and information fusion systems should enable the rapid calculation of branches and sequels without losing combat initiative. Further, employing evolutionary algorithms would, in theory, offer the potential for decision support systems to learn from actual combat experience and generate more flexible and effective operations plans with each iteration.

In practice, however, the research suggests this level of combat decision support remains aspirational. In one example from 2023, the authors state:

> We describe methods for encoding decision variables and decoding assignment plans, construct a reasonable fitness function, and employ a differential evolutionary algorithm to solve the problem. After optimizing combat missions based on mission and threat, *our model and method are applicable to generating static pre-war combat mission assignment plans*. These plans are assigned to available combat units sequentially according to a temporal logical relationship. *Wartime scenarios, where unexpected situations render the plan invalid and require rapid adjustment or regeneration, are not considered*.[35] (Emphasis added)

Even building on a foundation of decades of prior research, this passage reflects the limitations the process must still grapple with, limits that are directly proportional to the additional complexity and uncertainty generated by actual wartime scenarios. This suggests that the complex systems of combat operations calculations may generate optimal employment options at the lower levels needed for sustaining operations of limited scale supporting limited political objectives, but will likely still struggle to provide quality calculated complex joint operations optimization with combat-relevant timeliness for higher levels of complexity, and for sustained periods.

If employed for actual combat operations at its current stage of development, this suggests that the process will likely lead commanders to favor highly scripted, highly intense, but tightly time-bound operations with limited military objectives. This may be true for two reasons. First, because military operations are complex and fast-moving, the data that supports the algorithmic processes has a short shelf life. To maximize the utility of the algorithms and minimize the risk and uncertainty inherent in extended operations, operations would have to be limited to the reliability of the data on hand.

Second, and closely related to the first point, the execution of every military operation will change the overall combat situation. Accordingly, the priorities and weights assigned to various combat factors will necessarily change with each iteration of operations, as will the resources available to execute operations. This suggests that, for a campaign-level action to achieve a scientifically calculated degree of success, all major subordinate operations must be calculated, coordinated, and synchronized before execution. This dictates a top-down, supply-side approach to campaign planning and is not efficient for responding to the bottom-up, demand-side nature of actual combat operations. In other words, this system would tend to favor a rapid, intense, but limited series of operations in which the PLA could calculate a reasonable ability to seize and hold the initiative. The longer operations go on, the less able the system will be to keep up with the rapidly changing body of data, the less able the system will be to effectively bound and calculate around uncertainty, and the more likely the PLA would be to lose the initiative.

Taken together, the research suggests that this approach to operational planning provides its clearest advantages in executing short, sharp conflicts: waged with high intensity, but for limited objectives over limited periods of time. This approach would still yield results in prosecuting a larger, open-ended, major conflict, but its ability to generate optimized planning under such circumstances would likely be degraded in direct proportion to the scope and duration of the conflict.

Considering Potential Future Impacts of Artificial Intelligence

Three trends are apparent from this review of the PLA research literature on operational optimization. First, the trend towards developing ever more powerful optimization methodologies for PLA operations will continue. Second, the work will expand into ever greater levels of complexity. Third, the trend towards increasing speed and complexity in modern warfare will continue to drive the search for ways to compensate for the biological limitations inherent in human cognition.

AI has the potential to become the central focus for advancing all three trends. The existing body of literature is still trying to expand the number of variables and the volumes of data it can incorporate into developing methodologies, requiring greater levels of computing power. AI can assist both in identifying and weighting the variables that form the foundation of all optimization methodologies by analyzing past patterns of military behavior (especially the historical record of U.S. military behavior) and extracting key elements that might escape human consideration. At present, mission dissection and weighting is largely a human effort.

For operations at the higher levels of complexity, AI can assist where the existing literature continues to show shortcomings in linking and coordinating the different types of methodologies applied at the different levels that will be necessary for planning and managing higher-level, complex combined arms operations. This may be especially consequential if applied within the PRC concept of Systems Warfare. AI may be able to forecast critical weaknesses in the operation of complex systems, and to calculate when a combat dynamic may be able to affect these systemic inflection points and bring them to collapse sooner and more accurately than a human being could do. The human commander will still be necessary to guide the overall war, but the AI could identify and characterize opportunities, and offer options for exploiting them, more rapidly than any human could.

As they mature, AI-generated and AI-directed complex operations may allow PLA commanders to sustain combat initiative for longer periods with greater confidence. This could lead to changes in the current War Control doctrine that emphasizes fighting for limited objectives and limited periods of time. This, in turn, might change PRC leadership understanding of how much political gain could be available from the cost of employing their military capabilities.

AI already appears in important but limited roles in the body of literature examined in this study. It is key to managing unmanned aerial and maritime vehicle employment, and there are experiments using AI to replace human commanders in computer modeling algorithms designed to develop the next generation of optimization tools. PRC researchers are exploring the potential risk of AI in areas beyond the military. However, the role that AI currently plays could easily be eclipsed by future developments that see it moving ever closer to center stage in modern PLA operational decision-making, and in the national leadership's understanding of the cost-benefit calculations of future wars.

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ENDNOTES

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