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Nuclear Decision-Making, Complexity, and Emerging and Disruptive Technologies: A Comprehensive Assessment

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EXECUTIVE SUMMARY

- The complex interactions of emerging and disruptive technologies (EDTs) could significantly impact nuclear decision-making, particular in an escalating regional conventional conflict. Such conflicts may present governments with a range of nuclear decisions: whether to introduce a nuclear dimension to a crisis, whether to cross the nuclear threshold through limited nuclear use, how to respond to a limited nuclear attack, whether to expand the scope and intensity of initial limited attacks, and whether to escalate to an all-out nuclear war. At each decision point, EDTs create potential risks as well as rewards.
- EDTs are likely to influence *the context* for nuclear decision-making and the *choices* between different courses of action. EDTs could impact the context of nuclear decision-making by improving or degrading situational assessment, the ability to deliberate, and the ability to manage one's nuclear forces. EDTs could influence the choice between nuclear restraint or escalation by affecting the perceived strategic benefits, escalatory risks, and operational requirements associated with different courses of action.
- Even though particular combinations of EDTs could precipitate nuclear use in some scenarios, they could encourage restraint in others. The impact and relevance of the same combinations of EDTs might be different at various nuclear decision points. The availability of specific combinations of EDTs at different stages of a conflict would also vary because of the attrition and one-time-use nature of some capabilities. In later stages of a conflict, the decision maker's confidence in different combinations of EDTs would depend on their previous experience in using them.
- While the interactions of EDTs are likely to bring additional complexity to a nuclear decision-making process, EDTs are also not the only source of complexity. Broader strategic, military, operational, legal, moral, and emotional factors are also likely to play an important role. These factors may dominate decision-making in a range of potential cases.

RECOMMENDATIONS

- Decision makers should seek to understand the limitations and potential consequences, intended and unintended, of more widespread adoption of EDTs.

- Even if a comprehensive risk reduction agenda seems currently elusive, decision makers should focus on laying the foundation for risk reduction measures. Such efforts should cover a number of unilateral and cooperative measures.
- *Unilateral measures* to identify opportunities for risk management could include:
    - Improved risks assessments that seek to understand not only the 'good' but also 'the bad and the ugly.' This includes seeking better understanding of how EDTs could impact nuclear decision making during all phases of an escalating conflict.
    - Assessing the performance and resilience of EDT-dependent systems during nuclear deterrence posture reviews.
    - Incorporating greater reliance on EDT-enabled systems into nuclear exercises.
    - Building resilience into the elements of nuclear decision making which are likely to rely on EDTs.
- These unilateral efforts can highlight opportunities for *cooperative measures*, including political commitments, legally binding agreements, and cooperative dialogues to jointly identify problems and solutions.

INTRODUCTION

Military power is increasingly synonymous with leadership in emerging and disruptive technologies (EDTs). Motivated by the conviction that the mastery of EDTs will translate into significant strategic and military advantages, major military powers and their allies are racing to capitalise on the strategic and tactical promise of EDTs. One area of acute concern is the intersection of new technologies and nuclear weaponry. The introduction of new technologies into the nuclear decision-making process creates wide-ranging uncertainties about associated rewards and risks. Compounding this analytic challenge is the fact that modern militaries will almost certainly adopt several potential game-changing technologies simultaneously, integrating them in complex ways to accomplish operational tasks.

Scholars and experts from a variety of fields have already begun to think through the challenges that EDTs will pose for modern military competition, coercion, and warfare. This literature is rich and extensive, and it has generated a large body of insights relevant to nuclear decision-making.[2] Yet one of the shortcomings of the available studies is that they tend to examine the effects of individual categories of technology. The literature is easily divided into studies on AI and nuclear deterrence, quantum technology and nuclear deterrence, or space weapons and nuclear deterrence. What is missing from the literature is a holistic approach that addresses how nuclear decision-making could be influenced by the complex interactions of various EDTs. Another limitation of the literature is that it does not fully account for how the combined use of EDTs relates to broader non-technological considerations, objectives, and pressures associated with nuclear decision-making. Yet the context for making nuclear decisions and a decision maker's choice on the course of action are affected not only by the integrated use of various EDTs but also by cultural, political, strategic, operational, organisational, moral, and legal factors. Similarly, most studies lack an explanation of how the impact of multiple EDTs may change in the different phases of an escalating nuclear conflict. Some combinations of EDTs that may be relevant in the early phases of the crisis may become irrelevant or unavailable in the later stages of the conflict. This study seeks to fill these gaps by answering three interrelated questions:

- How might the complex interactions of EDTs impact nuclear decision-making at key phases of an escalating conflict?
- How might EDTs change the context and choices available during nuclear decision-making?
- Which combinations of EDTs will be the most relevant to nuclear decision-making?

The paper focuses on nuclear escalation resulting from a conventional conflict, which is generally seen as the most likely pathway to a nuclear conflict today. Such a conflict is likely to involve several nuclear decisions, not all of which will be limited to the decision to use nuclear weapons. These include the decision to introduce a nuclear dimension to a crisis through signalling, the decision to cross the nuclear threshold through limited nuclear use, the decision on how to respond to a limited nuclear attack, the decision of whether to expand the scope and intensity of nuclear strikes, and the decision to escalate to an all-out nuclear war. In considering these decision points, this paper focuses on the technological landscape as it might look in the

2025-2030 timeframe. The intent behind this timeframe is to highlight technologies and strategic dynamics that will confront the current generation of nuclear policy makers.

To illustrate the impact of the combined use of EDTs on the context of nuclear decision-making, the paper examines the potential positive and negative effects on a decision maker's situational awareness, ability to deliberate, and ability to manage forces. To visualise the impact of EDTs on a decision maker's choices, the paper examines how EDTs might affect the assessment of strategic benefits, escalatory risks, and operational requirements, ultimately pushing the decision maker towards nuclear resolve or restraint.

This paper consists of two parts. The first part provides a background for the analysis by explaining the key strategic considerations of the nuclear decision-making process, and how EDTs are relevant for the 'context' and 'choices'. It then identifies the key EDTs that, when used in a combined way, are likely to be the most influential in the 2025-2030 timeframe. The second part of the paper presents the analysis on how EDTs could influence the context for nuclear decision-making, and the choices between different courses of action. The conclusion highlights the broader implications of the findings for nuclear decision makers and summarises the answers to the three main questions of the paper.

Before proceeding, it is worth clarifying what a study of this nature can accomplish and what it cannot. First, although this report seeks to be applicable to any nuclear decision maker, we recognise that there are unique cultural, societal, political, and military considerations which influence individual states, decision makers, and/or scenarios. The operating assumption in this paper is that there are enough fundamental similarities and points of convergence at the strategic level to justify a generic discussion. Second, the report does not aim to provide a detailed technical discussion of different EDTs or explain every aspect of the nuclear decision-making process. Instead, our aim is to visualise and illustrate the potential rewards and risks associated with growing technological complexity. Finally, it is our hope that the following discussion can provide a foundation and intellectual stimulus for further efforts to better understand how the combined use of EDTs could impact nuclear decision-making.

THE APPROACH

The key nuclear decisions

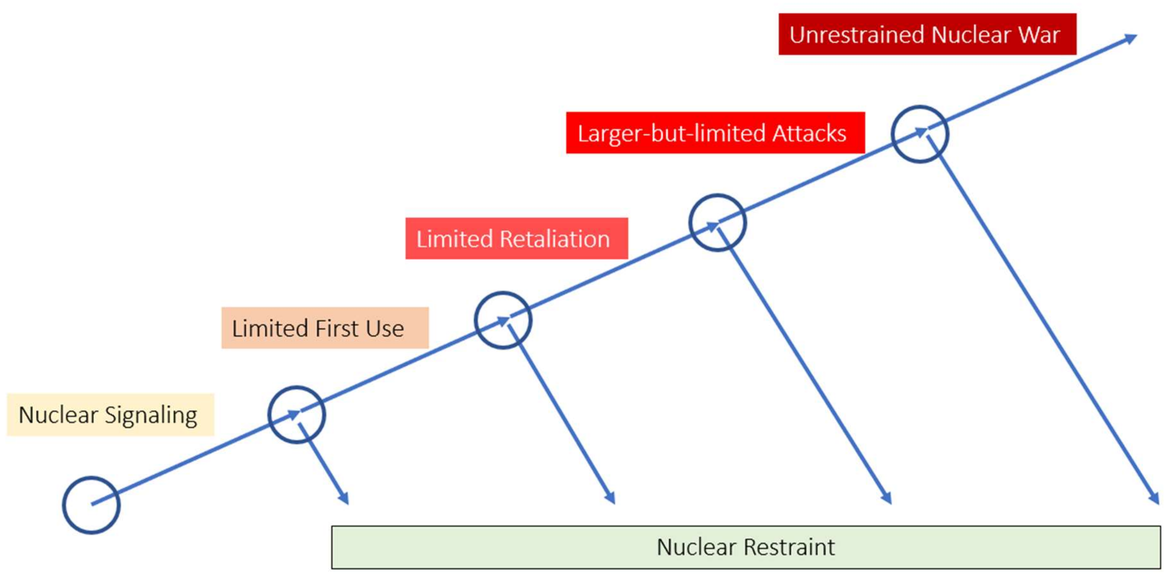
Analysing the impact of the combined use of EDTs requires an understanding of the evolving nuclear environment. In this regard, there is a growing consensus that the most likely pathway to a nuclear crisis or war is the escalation of a local or regional conventional conflict. Such escalation could occur in different geographic regions, including Europe and Asia.[3]

In such scenarios, the nuclear 'temperature' of the crisis or war could rise gradually as both sides steadily climb an escalation ladder.[4] Decision makers on each side are likely to be confronted with multiple nuclear decision points, possibly in close succession. The speed in which escalatory steps are taken would depend on the overall dynamic of the confrontation.

Although each regional conflict would be different, there are at least five key nuclear decisions that a decision maker may have to confront in the scenario of an escalating regional crisis with a nuclear-armed rival. In increasing order of intensity, they include:

- Whether to send (or respond to) nuclear signals;
- Whether to cross the nuclear threshold through limited nuclear use;[5]
- Whether to respond, and if so how, to an adversary's limited use;
- Whether to expand the scope and intensity of initial limited attacks;
- Whether to escalate to an all-out nuclear war.

Decision makers are likely to confront at least five nuclear decision points, denoted by the circles in Graphic 1:



CAPTION TEXT: Decision makers are likely to confront at least five nuclear decision points, denoted by circles in the graphic.

The complex interactions of EDTs could impact a decision maker's calculus at each of these decision points. Yet, EDTs alone are unlikely to have a definitive effect on nuclear decision-making because national leaders rarely make decisions based exclusively on technological factors. War remains an inherently political act and there are broader strategic, military, and operational considerations that might affect each of these decisions. Acting under the nuclear shadow, any decision-maker would likely be torn between rational calculations and volatile emotions. Their cost-benefit analysis might be coloured by feelings of indignation, vengeance, humiliation, or fear.

It is also important to note that the complex interactions of EDTs would impact a decision maker's behaviour against the backdrop of certain enduring features of nuclear strategy and operations.

First, in every major nuclear power, any decision about the movement, brandishing, or use of nuclear weapons, or the delegation of this authority, is likely to involve an affirmative decision by a national leader.[6] To safeguard this authority, all nuclear powers appear to have taken steps to prevent the unauthorised use of nuclear weapons.[7]

Second, nuclear decision-making is likely to be deliberative unless there is no time to convene a high-level discussion, for instance if an attack is already underway and a failure to act quickly is likely to result in significant negative consequences.[8] The more time there is to decide, the more deliberative the process is likely to be. Even in the case of a very short-notice attack, there is likely to be some deliberation.[9]

Third, even without EDTs, the decision-making process is likely to involve inputs from a variety of sources, including data from warning systems, intelligence systems, military personnel on the ground, presidential advisers, as well as military commanders and experts. Collecting, presenting, and disseminating these inputs will likely involve significant reliance on information technology. Technology might also be used to support decision-making by helping project the consequences of alternative decisions.

Fourth, even if technology enables very short-notice operational planning, nuclear decision-making is likely to continue to rely somewhat on pre-planned military operations.[10] Pre-planning helps ensure that military personnel using available forces—weapons, delivery systems, and enabling capabilities, such as aerial refuelling tankers—can strike necessary targets in wartime conditions. Even states that anticipate engaging in adaptive or short-notice planning for nuclear operations may find that some pre-planning is necessary to understand what kind of short-notice operations may be possible.[11]

Lastly, leaders are likely to place significant emphasis on the need for nuclear forces that can survive pre-emptive attacks to carry out retaliatory strikes. Many of the strategic advantages of nuclear possession depend on a nuclear power's ability to retain the option to attack even if attacked first.[12] Although different nuclear powers have interpreted this requirement for a 'secure second strike' capability differently, all of them recognise the importance of the basic idea and have developed systems to carry out nuclear attacks if the adversary makes an attempt to strike first.[13]

The nuclear decision-making context and choices

This study focuses on how both technological and substantive factors could affect the inputs and the outputs of a nuclear decision-making process. It does so by considering how the complex interactions of EDTs might impact the circumstances or *context* surrounding key nuclear decisions and the *choices* of alternative courses of action.

With regards to the decision-making *context*, experts on decision-making in business, economics, and social psychology all agree that it is an important factor in how people make decisions.[14] Context refers to factors that can affect how decisions are made but do not alter the decision maker's underlying preferences for any particular outcome. Such factors define how the pursuit of individual-level goals shift based on the environment. For example, people appear willing to make riskier bets to avoid losing a given amount of money than to win the same amount of money. The value of money to the individual is the same, but the context—whether one is losing or winning—has an important impact on the overall decision.[15]

The complex interactions of EDTs could make a difference in the decision-making context by improving or degrading a decision maker's ability to assess the situation, deliberate about the optimal course of action, and control one's forces and execute pre-planned operations. They could do this in various ways. The combined use of EDTs could impact a decision maker's situational awareness—both positively or negatively—by affecting the ability to assess the intentions, capabilities, and behaviours of the adversary; by changing the information environment in which the decision maker operates, including domestic political support; or by affecting the ability to detect attacks, distinguish between real and false alarms, or conduct damage assessment.[16] The decision maker's ability to deliberate could be changed by the availability of time to decide; the ability to assess alternative courses of action and plan new operations; or the ability to communicate and coordinate with allies. The complex interactions of EDTs could also impact a decision maker's ability to control forces and execute missions by interfering with nuclear command, control, and communication (NC3).

Any decision maker that confronts a nuclear scenario must weigh the advantages and disadvantages of the *choices* available, relative to the circumstances. They must explicitly or implicitly answer the question of whether securing vital interests demands showing nuclear resolve or whether the same goals can be achieved by exercising nuclear restraint.

The complex interactions of EDTs could affect a decision maker's choice on whether to pursue nuclear resolve versus restraint, by impacting their influence on strategic benefits, escalatory risks, and the operational effectiveness of different options. EDTs could impact a decision maker's assessment of which course of action is likeliest to achieve the desired strategic objectives. The combined use of EDTs could encourage or dissuade a decision maker from a particular course of action by decreasing or increasing the risks of accidents, mishaps, misperception, and miscalculation that could lead to unwanted escalation. Likewise, EDTs could alter the decision maker's choices of the preferred course of action by having an impact on the lethality, flexibility, and reliability of different military operations.

The analytical framework for this paper is visualised in Table 1:

Key Decision Points	**The Impact of the Combined Use of EDTs on:**					
	Context			**Choices**		
	Situational assessment	Ability to deliberate	Ability to manage forces	Strategic benefits	Escalatory Risks	Operational enablers and constraints
Signalling	+/-	+/-	+/-	+/-	+/-	+/-
First Use	+/-	+/-	+/-	+/-	+/-	+/-
Response	+/-	+/-	+/-	+/-	+/-	+/-
Larger-scale, less than	+/-	+/-	+/-	+/-	+/-	+/-

existential attacks						
All-out nuclear war	+/-	+/-	+/-	+/-	+/-	+/-
	+ Improved/ - Degraded			+ Restraint/ - Resolve		

EDTs and complexity

Many EDTs have the potential to reshape international politics by changing the nature of military and economic power.[17] These include technologies that could shift the cost of attacking compared to defending, technologies that render some forms of military power completely obsolete or irrelevant, technologies that change the nature of economic production, and technologies that facilitate innovation and further technological development.

Although studies vary in their focus, most of them concentrate on the medium term, which includes EDTs that are likely to mature in the 2040s, with early adoptions beginning in the mid-2030s and late adoptions by 2050. This is the perspective taken by the NATO Science & Technology Organization, the U.S. National Intelligence Council's Global Trends Project, and other notable efforts.[18] Besides, there are a handful of studies that focus on the longer term adoptions, beginning at least 30 years into the future.[19]

There is significant convergence within the literature on which potentially game-changing technologies will be mature or widely adopted by 2030, and which will still be in the early stages of development because of barriers to widespread adoption. The latter category includes quantum supremacy (the development of quantum computers capable of solving problems that are impossible to solve using current computers); some forms of quantum sensing; and directed energy air and missile defences. In contrast, the focus of this report is on the technologies that are likely to make a difference to nuclear decision-making in the 2025-2030 timeframe. These include:

- **Artificial intelligence and big data analytics.** Machine learning tools, a subset of the broader discipline of artificial intelligence, can help analyse massive amounts of intelligence, surveillance, and reconnaissance (ISR) data; contribute to actionable intelligence and targeting information; support decision-making; and facilitate command and control (C2). Machine learning is essentially a very powerful data analysis tool used to enhance other technologies. For instance, neural networks, a machine learning technique that mimics the processing structure of the brain, can be used to train existing computer graphics technology to produce hyper-realistic videos ("deepfakes"). They can also be used to analyse sensor data, optimise equipment maintenance schedules, and support decision-making and military planning.[20]
- **AI-enabled cyber operations.** Artificial intelligence can increase the efficacy of offensive and defensive cyber operations. For instance, machine learning can be applied to develop 'self-healing networks' that automatically identify suspicious activity and cue organisations to patch vulnerabilities and respond to attacks.[21] Conversely, AI can facilitate better phishing campaigns, vulnerability scanning, or malware generation.

Predictive analytics tools could also help identify threats originating from the human-machine interface by identifying potentially problematic users.[22]

- **Cheaper and smarter space assets and space weapons.** Several militaries already rely heavily on space-based early warning, intelligence, and navigation (positioning, navigation, and timing or "PNT"), and communications systems. In the coming decade, the economics of space exploitation are likely to shift dramatically. Private and public sector innovation is lowering the cost of deploying sophisticated sensing and communications capabilities in various orbits while the integration with other technologies, such as edge computing or self-healing networks, is expanding the resilience and capability of space systems.[23] At the same time, militaries are improving their ability to fight in space using both kinetic (weapons that cause damage through physical impact) and non-kinetic space weapons. Some non-kinetic anti-satellite systems have reversible effects while others, such as lasers, can cause permanent damage to satellite components. Militaries are also testing dual-capable systems, such as spacecraft that can grab or dock with satellites.[24]
- **Autonomous systems.** Autonomous systems are physical or digital systems that can engage in self-directed behaviour in accordance with delegated and bounded authority.[25] There is a spectrum of self-directed behaviour, from the fully manual to the fully independent. As such, autonomy encompasses partially autonomous systems that ask human users to approve a pre-defined course of action, based on defined circumstances, as well as fully autonomous systems that could independently assess the environment and devise courses of action without direct human input or supervision. Greater levels of autonomy are enabled by sensors, communications, on-board data processing, and software, including AI applications.[26] States are pursuing autonomy for a variety of reasons, but a recurring motive is the desire to reduce the cognitive load and physical demands on humans associated with important but complex missions, such as long-endurance missions, pattern recognition, deconfliction, and coordination, etc.[27]
- **Hypersonic weapons.** Hypersonic weapons fly at least five times the speed of sound. By this definition, many ballistic missiles are technically hypersonic weapons. Current hypersonic weapons development is focused on four kinds of systems: hypersonic cruise missiles, manoeuvring hypersonic glide vehicles, hypersonic aircraft, and hypersonic rail guns, although most of the interest in the policy community is on the first two. Because of their in-flight manoeuvrability and high speeds, both weapon systems can potentially evade detection by early warning and defensive systems while precluding precise predictions of intended targets.[28] Although hypersonic vehicle technology is not new, current efforts are facilitated by improvements in computational modelling, materials science, and new propulsion technologies.[29]
- **Quantum technology.** Extensive private and governmental research is underway to exploit the properties and phenomena of quantum physics for computing and other tasks. The ultimate goal of quantum computing research is the ability to perform computations that current computers are unable to do on useful timescales. True quantum supremacy could enable the breaking of current unbreakable cryptographic ciphers. Most experts believe that useful quantum computing will not arrive by 2030. However, other applications of quantum technology may be in use in the next decade,

particularly quantum sensing, positioning/navigation/timing, and quantum communications. Quantum sensors could allow for more precise detection of vessels or aircraft at ranges or in conditions that confound existing sensor technology. Quantum PNT systems can enable navigation without recourse to global positioning satellites or in difficult environments. Quantum computing would enable secure communications even if quantum computers become able to defeat current cryptographic methods.[30]

Although each of the EDTs discussed above could bring significant changes, military planners believe that the maximum impact of EDTs will come from the integrated use of multiple EDTs to accomplish discrete operational tasks.[31] That is, in reality, none of the above EDTs is likely to contribute to nuclear decision-making in isolation. States are likely to adopt multiple EDTs simultaneously, using them in different combinations to accomplish particular objectives. Broadly speaking, EDTs are likely to be linked to provide value to nuclear decision makers by improving their ability to understand the external environment, identify courses of action, decide on a course of action, and execute it. The contribution of EDTs to the first two elements supports the decision-making context while the last two influence decision makers' choices on a course of action.

A cautionary note must be made in assessing the implications of combinations of different EDTs. Fully understanding the impact of these technologies is difficult because of the complexity associated with the combined use of EDTs. There are a number of fundamental aspects of this complexity.

Each combination of EDTs could produce effects that are different from those of individual EDTs. It is not possible to ascertain all possible consequences of different combinations of EDTs based on assessing the individual impact of each EDT. In other words, for a given combination of EDTs, 'the whole is different than the sum of its parts'.[32] Similarly, different combinations of EDTs are likely to interact with each other and the decision-making process in non-obvious ways. As a result, no analytic exercise can fully anticipate the ways that EDTs might impact a decision-making process. This fact limits the ability for deductive analysis to fully predict real world outcomes.

The complex interactions of EDTs are likely to have impacts across the spectrum of conflict, from day-to-day 'peacetime' interactions through high-intensity war. The use of EDTs in one phase of the conflict could also have impacts on the other phases of the conflict. For instance, how a technology is used in peacetime could affect how it is used in war, or how other states anticipate its use in war. The combinations of EDTs that have a decisive impact on the context of a nuclear decision, or the choice of alternative course of action in one phase of the conflict, might become unavailable or irrelevant in later phases.

Last but not least, nuclear powers armed with EDTs will face other nuclear powers armed with their own technologies. How each side acts will depend not only on its own capabilities and objectives but on those of the other side. This interactive process will likely involve various degrees of human-human, human-machine, and machine-machine interaction as decision makers attempt to act strategically while contending with their own technological systems and the interaction of their systems with the adversary's technological systems. All these interactions will take place in an uncertain environment that is obscured by the 'fog of war'.

THE ANALYSIS

Decision on whether to exercise restraint or signal nuclear resolve

Any crisis that involves nuclear weapon states or nuclear alliances is a nuclear crisis. The mere existence of nuclear weapons, even if they remain in the background, influences the choices and risk calculations of decision makers.[33] Political leaders can, however, make a conscious choice to move nuclear capabilities to the forefront. This could involve sending nuclear signals to an opponent through official and unofficial statements, nuclear exercises, or increasing the alert status of nuclear forces.

Even without considering the effects of EDTs, the choice between demonstrating nuclear resolve or exercising nuclear restraint is complex. The reception of such 'messages' would be contingent on the other side observing them - yet some signals may only be observable to the other side at certain times and with certain capabilities. The interpretation of nuclear signals is also a complex process, involving inferences about the consequences and the underlying intent associated with a signal. For instance, raising the readiness of nuclear forces could signal a willingness to escalate to nuclear use, as well as a general acceptance of the risk that such actions could provoke escalation by the other side. Thus, alerting forces could be seen as a signal of resolve. On the other hand, such signals could reflect bureaucratic preferences rather than a deliberate attempt to send a message. For instance, militaries may have doctrinal preferences for bringing all available military tools to bear early in a crisis, which could result in a perceived signal that was solely intended to make certain forces available. This would send a message, but not the intended message.

In making the decision to send or respond to a nuclear signal, a decision maker would therefore have to consider several factors. Would sending nuclear signals strengthen or weaken a state's bargaining position? Would an adversary sense weakness in the failure to respond to a nuclear signal? Is there domestic political pressure to introduce a nuclear dimension to a crisis? Alliance relations could also influence a national leader's deliberations: demonstrating nuclear resolve could reinforce the credibility of one's security assurances, but it could also unnerve some allies who might favour nuclear restraint.

How decision makers work through these considerations depends on the decision-making context, namely their ability to make sense of the environment, and their understanding of the advantages and disadvantages of the available choices.

EDTs and the decision-making context

EDTs will likely have a major impact on the context of decision-making through their effect on situational assessment. The standard approach to situational awareness is to rely on human experts to synthesise assessments of adversary intentions and behaviours with military intelligence on the movement of adversary forces. The latter is typically gathered from a mix of technical and human sources, including satellite imagery, reconnaissance aircraft, and personnel on the ground. Many of these collection platforms may be difficult to move or 're-task' quickly, limiting the scope of data collection. Finite numbers of collection platforms may also be in demand by multiple bureaucratic actors. The synthesis of the data collected from these platforms happens at the speed of human cognition and action, with analysts relying on mental models and their own expertise to filter signal from noise. Analysts must present their assessments in a format amenable to decision makers' preferred style for information consumption, such as a written or oral briefing.[34]

EDTs could dramatically change this approach in several ways. The complex interactions of various EDTs could significantly improve situational assessment during a crisis by providing decision makers with more precise or accurate insights into whether nuclear signals might have an impact on adversary behaviour and how adversaries might react. For example, autonomous intelligence and data collection platforms could provide decision makers with up-to-date information on adversary capabilities and actions. These platforms could be re-tasked quickly to move to other areas. AI-enabled big data analytics could then analyse these different streams of intelligence at high speed. This could contribute to estimates of an adversary's intentions and the military balance.

EDTs could also support decision making by helping generate alternative courses of action. Typical operations research involves days, weeks, or months of study, design, and refinement.[35] Advanced applications of AI and machine learning (ML) for decision support and ISR, combined with space systems that enable better communication can provide a continuous flow of actionable information that could be fed directly to simulation software, helping generate alternative courses of action that are tightly coupled to the real-world context. These decision-support tools may also facilitate consensus-building internally or among alliance members by supporting discussion of alternative courses of action.

EDTs can also be applied to help defeat adversary attacks through direct defence reducing incentives for hasty decisions. For instance, an AI-enabled battle network can be used to track adversary satellites and surveillance aircrafts, correlate their locations with the locations of one's own forces, and use the data to cue one's air defence forces.

Yet the EDTs could also negatively affect the decision-making context. Improved situational awareness and decision support tools could affect decision making by facilitating overconfidence. The seeming sophistication of digital technologies can create an aura of authoritativeness and objectivity that could lead decision makers to put significant trust in technological judgments. Yet decision makers may have a poor understanding of the inner workings of the algorithms enabling improved situational awareness or decision support tools. Even the experts who devised the algorithms may have difficulty explaining how an algorithm produced a particular result.[36] Decision makers may therefore exhibit undue trust and insufficient scrutiny toward digital tools.

Alternatively, if they produce a flood of information or generate contradictory insights, the use of EDTs for situational awareness and decision support could contribute to confusion and decision paralysis. Several different approaches to integrating EDTs for situational awareness may be in use simultaneously, for instance by intelligence agencies, military organisations, and the national leader's own staff.[37] Each could leverage different algorithms and data collection methods, potentially producing contradictory findings that do not suggest a clear course of action.

In addition, the use by adversaries of the combinations of technologies that compress decision times (such as hypersonic missiles, swarm robotics, autonomous systems, or kinetic counter-space capabilities) make it very challenging for national leaders to assess, deliberate, and take action in a timely manner. Adversaries could use AI-enabled cyber operations in tandem with kinetic and non-kinetic counter-space systems to degrade and manipulate the information that is available to the decision maker. A volatile information environment, replete with fake news and deep fakes, would likely shape public perception of the crisis and therefore a decision maker's own calculations. The very same EDT capabilities could also degrade communication with allies and undermine the ability to develop new military options.[38]

Additionally, EDTs could impact the decision maker's ability to control one's forces and execute pre-planned signalling operations during the crisis, which would affect decision makers' estimates of the potential success of different courses of action. In this regard, resilient space-based assets could provide more reliable communication channels and increase the resilience of NC3 systems that are crucial to provide a decision maker with the ability to communicate with forces. Similarly, self-healing networks and advanced communications could provide greater confidence to decision makers that they could exert enduring command and control over their forces, even after an attack. In contrast, the combined use by an adversary of AI-enabled cyber operations, non-nuclear precision strike, and kinetic and non-kinetic counter-space weapons could destroy or interfere with the operation of C2 systems, significantly undermining a decision maker's abilities to communicate with their own forces and signal resolve or restraint in a crisis.

In summary, EDTs can contribute to the nuclear decision-making context by facilitating deliberate decision making or hindering it. There are three pathways through which they could do so: by improving decision makers' situational awareness (and confidence in situational assessment), by facilitating consultation and the consideration of alternative courses of action, and by improving decision makers' assessments of the performance of their own forces.

EDTs facilitate decision making and improve situational awareness	**EDTs hinder decision making and increase confusion**
EDTs improve situational awareness by providing better real-time information (or added confidence) about adversary intentions, behaviours, and capabilities.	EDTs hinder decision making by introducing information overload, conflicting information, or diminishing decision maker confidence in situational awareness and assessment
EDTs support development and deliberation on alternative courses of action	EDTs hinder option development, deliberation, and consultation
EDTs improve confidence in one's own forces	EDTs degrade confidence in one's forces

These basic considerations about EDT's effects on situational awareness, the ability to deliberate and develop alternative courses of action, and the ability to use one's forces are relevant for all five decision points. Thus, the above table is applicable to all subsequent discussions about the context.

EDTs and decision-making choices

EDTs will also likely impact decision makers' judgment about the strategic benefits, escalatory risks, and operational requirements associated with different courses of action. If greater use of EDTs helps convince decision makers that nuclear signalling can produce strategic advantages with minimal operational constraints and escalatory risks, they might tilt the balance in favour of nuclear signalling. Conversely, if EDTs contribute to an assessment that there are no advantages - and many downsides - to nuclear signalling, they may contribute to nuclear restraint. The following table summarises this reasoning.

EDTs and incentives for nuclear signalling	**EDTs and incentives for nuclear restraint**
EDTs help increase the perceived strategic advantages of nuclear signalling	EDTs do not enhance the strategic appeal of nuclear signalling while providing alternatives
EDTs help manage or minimise the escalatory potential associated with nuclear signalling	EDTs can exacerbate the potential for escalation
EDTs create operational requirements for nuclear actions and increase confidence in the success of a signalling operation	EDTs minimise the operational downsides of restraint and reduce confidence that signalling will succeed

On the strategic advantages of nuclear signalling

EDTs can facilitate the use of exercises and demonstrations to send nuclear messages. They could also increase the success of such operations by increasing the prominence and clarifying the meaning of a nuclear signals. For example, hacking adversary's space reconnaissance assets and pointing them at ongoing nuclear exercises could drive home the point that these exercises are important. Improved information operations, supported by deepfakes, powerful botnets, and other tools, can also reinforce the sense that nuclear escalation is very likely if the adversary crosses some red line.

EDTs can also enhance decision makers' confidence in the ability of nuclear threats to decisively influence an adversary's decision making. Space assets, autonomous and uncrewed surveillance systems, and data analytics can help reveal targets that are highly valued by the adversary and contribute to its ability to sustain military operations. These targets could then be held at risk with nuclear weapons, and signalling campaigns could be devised to communicate a willingness and ability to attack these targets.

There are certain limitations to the role of EDTs as an alternative to nuclear signals. While nuclear signals are designed to be visible and clearly communicate intent, the signals sent through the combined use of EDTs might not be read by an adversary. Because the destructive effects of EDTs are sometimes reversible and less catastrophic than nuclear weapons, the recipient of such signals may be unimpressed by them. In addition, employing certain EDTs, might not be available on a short notice or on the scale necessary to send the desired message. Employing offensive cyber tools for messaging may also make these tools unavailable if a crisis escalates into a conflict as the maximum battlefield effect of these systems can only be achieved if the capability is not revealed in advance. A related problem with multi-domain signals is linkage. For instance, war games suggest that cyber signalling is difficult because observers tend to have trouble linking action in cyber space to real-world stakes or behaviour.[39]

Despite these limitations , EDTs might be preferrable to some decision makers because they may see similar uncertainties in nuclear signalling. Nuclear signals have a mixed track record. For instance, although Soviet leaders noticed the large-scale U.S. nuclear alert undertaken by the Strategic Air Command during the Cuban Missile crisis, they seem to have been more impressed by the general U.S. military mobilisation around the Caribbean.[40] At other times, signals intended to send carefully calibrated messages have been ignored, discounted, or misperceived by their intended recipients.[41] Decision makers may therefore opt for EDTs before reaching for nuclear signalling. For example, demonstrating multidomain capabilities through testing of kinetic anti-satellite capabilities, temporarily disabling adversary's air defence units through cyber operations or deploying autonomous systems could send a strong message about resolve to act if a crisis escalates into a conflict. This could have a deterrent effect by demonstrating the military capabilities available to the adversary.

EDTs and escalatory risks

There are many ways EDTs can facilitate nuclear messaging by decreasing potential escalation risks. For example, technology can create more reliable channels of communication between decision makers, which can allow rival governments to more clearly communicate intent and ensure that a demonstration of resolve is not misunderstood by the opponent. Yet, EDTs could also heighten the risk of unwanted escalation, potentially weakening the appeal of nuclear signals. Nuclear messages in conjunction with the employment of different combinations of EDTs could be misinterpreted by an adversary. For example, cyber operations against NC3, in tandem with attempts to temporarily blind adversary satellites during ongoing nuclear exercises, may be misinterpreted as preparation for a nuclear attack. Whether such signals are misinterpreted, however, is likely to depend on the broader context and the prior relationship between the belligerents. If national leaders are generally suspicious about each other's intent, and there are parallel (but possibly erroneous) signals that an attack is likely, an unwanted escalation is more likely.

EDTs as operational enablers and constraints for nuclear messaging

EDTs could also create or ameliorate the perceived need to engage in nuclear alerts, force movements, and other actions. Depending on states' particular nuclear postures and capabilities, decision makers concerned about fast-moving attacks could have strong incentives to put their nuclear forces on high alert and disperse them. This could send strong nuclear messages even if this was not the original intention of the decision maker.

In certain circumstances, however, EDTs may lessen operational requirements for nuclear signalling. For example, the integration of improved computing, quantum encryption, and machine learning could allow decision makers to monitor weapons and communication links in real time, increasing their confidence in the ability of their forces to perform when used, and remain secure otherwise. EDTs could also help mitigate the risks created by compressed decision times and improved first-strike capabilities. Quantum sensing and a network of autonomous anti-submarine aircraft could be used to stress-test one's sea-based deterrent forces, for example. Advancements in integrated air and missile defence systems (IAMDS) and early warning can significantly augment defences and make it more difficult for adversary strikes to reach their targets.

Decisions about nuclear first use

The decision to use nuclear weapons first in a war is one of the most consequential decisions that any nuclear decision maker can ever make. Doing so would cross the nuclear threshold for the first time since 1945, undermine the nuclear taboo and heighten the risks of an all-out nuclear war.

Nuclear first use can take different forms, ranging from a nuclear demonstration that would not cause any significant physical destruction or loss of life to a more consequential (but still limited) attack that would destroy critical civilian or political infrastructure while minimizing casualties and widespread environmental contamination. The threshold for what would be considered limited is subjective. What could be considered limited nuclear use to one person or state could be seen as highly destructive to another.

A variety of motives might back up a decision to engage in a discriminate use of nuclear weapons. For instance, nuclear first use could be a last resort if a country is conventionally defeated or on the verge of defeat. Nuclear use could serve to shock an adversary into de-escalation by 'sobering but not enraging' adversary leaders.[42] Limited use may also be driven by warfighting requirements for destroying certain targets; limited nuclear strikes could alter the military balance enough to turn the tide in the conventional fight. Decision makers may also resort to limited use to deter major non-nuclear attacks, such as an attack on critical civilian infrastructure that causes significant loss of property and life. Lastly, a decision maker may resort to a nuclear strike driven by the fear that an adversary is preparing for a disarming first strike. Limited nuclear use might be a result of any of these considerations, or it may be driven by a combination of them.

Any decision maker is likely to be under enormous political, military, public, and moral pressure to contemplate a limited nuclear use in an escalating, and potentially very costly, conventional war. While some advisers and public voices will call for restraint, others will call for using any available tool to spare lives and secure victory. As with the decision on whether to demonstrate nuclear resolve or restraint in a crisis, the combined effects of EDTs could impact a decision maker's assessment both in favour and against nuclear first use.

EDTs and the decision-making context

As in the scenario of nuclear signalling, EDTs could impact the context surrounding a first use decision by affecting decision makers' confidence in the assessment of adversary intent, capabilities, and actions, by facilitating deliberate decision-making, and by influencing decision makers' confidence in the ability to control one's forces.

First, EDTs could support assessments of whether limited use would decisively induce an adversary to de-escalate. Such assessments could draw on situational awareness and data fusion technologies to examine the impact of limited use on adversary decision makers, domestic politics, and the military balance. In some circumstances the combination of EDTs that support better situational assessment could disincentivise a decision maker from nuclear use by providing more accurate data on the situation on the battlefield than in a situation in which the decision maker did not have such technologies at its disposal.

Second, EDTs could facilitate deliberate decision-making about limited use under time compressed conditions. In addition to supporting consultation with allies and internal stakeholders, EDTs could be used to assess the strategic and military impact of a range of nuclear and non-nuclear courses of action. Such decision support tools could lower the nuclear threshold by highlighting the potential advantages of nuclear escalation. For instance, decision makers could use real time data on adversary military activities to assess the impact of limited nuclear use on the prospects for defeating adversary conventional forces. Similar assessments could be done to minimise the risks of collateral damage and damage to one's own forces or allied forces. While it is uncertain how a decision maker's own predilections and 'gut feeling' will interact with advice provided by machines, a decision maker may be heavily influenced by systems that provide a compelling pathway to avoiding defeat, prologuing a conflict.[43]

Third, the decision to use nuclear weapon first could also be shaped by a decision maker's calculation on their ability to control nuclear forces and execute a first nuclear strike. This calculus might be impacted by the use of technologies that accelerate the conflict and compress decision times (such as hypersonic missiles, swarm robotics, autonomous systems, or kinetic counter-space capabilities) and also by those technologies that incentivise early and decisive steps to achieve dominance in the initial phase of war. The concerns that an adversary's non-nuclear actions might undermine the ability to execute nuclear strikes later in a conflict could push the decision maker to use nuclear weapons earlier than anticipated. Alternatively, if the adversary succeeded in using EDTs to significantly undermine the decision-maker's ability to communicate with its own nuclear forces, the decision maker might lose confidence in the ability to execute limited nuclear strike. This might convince a decision maker to refrain from nuclear strikes.

EDTs and decision-making choices

EDTs could impact the prospects for limited first use by affecting how decision makers assess the advantages, disadvantages, and requirements of first use relative to other courses of action.

EDTs and incentives for a nuclear first use	**EDTs and incentives for nuclear restraint**
EDTs contribute to perceived strategic advantages of limited use	EDTs provide alternative path to achieving political and military goals
EDTs provide greater confidence in managing the risks of further escalation	EDTs heighten concern that escalation after first nuclear use is more likely
EDTs increase confidence in the success of limited use and help mitigate operational consequences	EDTs decrease confidence in a successful first strike and create operational challenges

EDTs and the strategic appeal of limited use

In theory, leveraging the combined effects of EDTs may provide an alternative to a limited nuclear strike to avoid military defeat or inflict one's own will on an adversary to finish the conflict on favourable terms. Temporary disruption of an adversary's C2, including NC3, ISR capabilities, and communication lines through AI-enabled cyber operations or non-kinetic counter-space attacks could send a message to an adversary about the risks of continued fighting, while also forestalling a conventional defeat. EDTs may also augment non-nuclear operations to generate effects similar to a limited nuclear strike. Different combinations of AI-enabled cyber strikes, kinetic and non-kinetic counter-space attacks, and non-nuclear precision strikes, including hypersonic missiles, could destroy or disrupt an adversary's C2 nodes, military infrastructure and forces. The destructive effects of this would be comparable to a nuclear attack, in terms of the military effect.

Under certain circumstances, the combined interactions of EDTs by an adversary could deter states from attempting a limited nuclear attack. For instance, by fielding a high-density integrated air and missile defence network that takes advantage of AI-enabled ISR data and swarms of interceptors, an adversary could convince an attacker that a very limited nuclear attack would fail. The attacker would then have to consider whether to back down or conduct a larger nuclear strike, risking further escalation. Both scenarios present difficult choices and could convince an attacker to favour restraint.

Although non-nuclear capabilities supported by EDTs could generate comparable military effects to a nuclear attack, they may have less psychological impact than nuclear weapons. Nuclear weapons have a unique political and symbolic cachet that is not yet matched by any conventional weapon. Decision makers may thus find that a nuclear option stands alone among the alternatives.

EDTs might also enhance the appeal of nuclear escalation. Pairing a nuclear attack with operations in other domains could amplify the psychological and military impact while limiting the ability of the adversary to respond quickly. EDTs could also be used to fine-tune the targeting of a nuclear attack for maximum effect.

EDTs and the escalation risks of limited first use

EDTs could help manage the escalation risks of a limited nuclear attack in several ways, including those discussed above. In addition, EDTs could help manage escalation risks by reducing the collateral damage of a nuclear attack. For instance, a limited nuclear attack could be made more limited by pairing the strike with non-nuclear attacks and attacks in space and cyber space. Such an attack might generate a larger military impact while still leveraging the psychological impact of crossing the nuclear threshold. EDTs could also reduce escalation risks by facilitating the ability of the targets of attacks to respond with restraint. Hypersonic strike systems that avoid missile defences could allow limited attacks to proceed without a preceding campaign to physically destroy an adversary's air defences. EDTs could also facilitate post-attack assessments by providing real-time information on effects and adversary responses.

Conversely, heavy reliance on EDTs could also increase the escalation risks of limited use. Even with direct communication channels, an adversary may perceive a limited nuclear strike as a prelude to a disarming counter-force strike, provoking an array of responses that limit the ability to further control the pace of fighting. Finally, EDTs might create unanticipated vulnerabilities that reduce the availability of alternative courses of action while exacerbating escalatory pressures after nuclear use.

EDTs and operational enablers and constraints

The complex interactions of EDTs may impact a decision about nuclear first use by influencing the calculation on an attack is likely to succeed. A war conducted under the shadow of EDTs could be a war in which offense has an advantage. AI-enabled ISR capabilities could make it easier to locate different adversary targets, including mobile weapon systems. New strike systems, including hypersonic glide vehicles, could offer new options for taking advantage of surprise and suppressing an adversary's air and missile defence systems. Counter-space weapons and cyber tools could disrupt an adversary's defences and C2 systems. Also, new nuclear weapons with high accuracy and very-low yield configurations might limit collateral damage. In such a scenario, the combined effects of different EDTs may increase decision makers' confidence in conducting a nuclear first strike.

EDTs can also pose threats to the survivability of nuclear forces that could give decision makers pause when it comes to crossing the nuclear threshold. If EDTs allow both sides in a nuclear rivalry to better target the other's forces, both sides may see an incentive to preserve the tradition of nuclear non-use as a way of preserving crisis stability. If limited use is seen as a prelude to a war of mutual nuclear attrition, decision makers may shy away from first use despite the potential strategic advantages.

Decision about how to respond to limited first use

There are as many dilemmas in deciding how to respond to a limited nuclear attack as there are in the decision to be the first to cross the nuclear threshold. On the one hand, a failure to respond with nuclear weapons would call into question the very foundation of a state's nuclear strategy and could embolden the attacker to use nuclear weapons again. A failure to respond would also send a message to other nuclear powers that nuclear weapons could be used with impunity. On the other hand, retaliation would do nothing to reverse the damage caused by nuclear weapons. Instead, it could precipitate an escalatory process that could culminate in the destruction of entire continents. A nuclear response may also be militarily unnecessary if the target of the first attack was on the cusp of winning a conventional war. The target of the first attack might therefore conclude that the best response to attempted nuclear coercion would be to show that it would do nothing to forestall a conventional defeat. Decision makers would be confronted with all of these questions and many others. In principle, the decision about which option to choose will be primarily driven by the political and military goals that the decision maker wants to achieve. These could include strategic considerations, but also ethical, legal, domestic political, and alliance factors.

In practice, a decision maker in this situation has four hypothetical options: in-kind and proportionate retaliation; a significantly larger nuclear retaliation; a separate non-nuclear response; or restraint, which in the context of a conventional war could involve the continuation of existing and planned campaigns.

EDTs and the decision-making context

As before, the effects of EDTs on situational assessment could provide a better understanding of adversary intent and might dispel confusion about the scale and intended target of an incoming strike, decreasing pressure on a decision maker to launch nuclear weapons on warning. On the other hand, a decision maker might be forced to make a premature decision to retaliate if an adversary takes advantage of EDTs to obfuscate the scope and target of an attack.

The complex interactions of EDTs might also impact the decision on how to retaliate by providing greater clarity to a decision maker about the damage created by the adversary's nuclear use. A decision maker, however, would have to balance this assessment with public expectations on how to retaliate, which might be manipulated by the information operations of an adversary or third parties.

As with the previous decision points, the available decision-support tools could both strengthen a decision maker's deliberative process, or they could also create overconfidence or appear useless in the context of the growing fog of war. However, the extent to which a decision maker would trust the advice from a decision-support tool is likely to be heavily influenced by a decision maker's experience in the earlier phases of the conflict.

While in the previous two decision points, the EDT effects on situational assessment and deliberations were the dominant factors, as the intensity of the conflict grows, the ability to execute nuclear decisions becomes more influential. At this stage of the conflict, the command and control of nuclear forces could be impacted not only by the use of EDTs but also by the initial nuclear attack of the adversary.

EDTs and decision-making choices

EDTs could also influence a decision maker's choice of which response option would be the most appropriate for achieving the desired political and military objectives. Decision makers will be confronted with a bevy of emotional, prudential, and political arguments for and against a nuclear response to a limited nuclear attack. EDTs may contribute to all of these. EDTs are also likely to impact decision makers' assessments of the strategic impact of a nuclear response, the prospects for further escalation, and the operational constraints surrounding the choice of a response. The below table summarises the considerations that might bear on how a decision maker might respond to limited nuclear use by an adversary.

EDTs and incentives for proportionate nuclear retaliation	**EDTs and incentives for disproportionate nuclear retaliation**	**EDTs and incentives for a non-nuclear response**	**EDTs and incentives for strategic restraint**
EDTs enable a proportionate nuclear response and diminish the appeal of other responses	EDTs enable a larger nuclear response and diminish the appeal of a	EDTs enable a non-nuclear response that achieves strategic goals and	EDTs enable restraint and diminish the appeal of a strategic

	limited nuclear or non-nuclear response	diminish the appeal of a nuclear response	nuclear or non-nuclear response
The risks of further nuclear escalation are more manageable	The risks of further nuclear escalation are more manageable	The risks of further nuclear escalation are more manageable	All other options involve unacceptable escalation risks
The combined use of EDTs enables in-kind and proportionate nuclear response	The combined use of EDTs enables in-kind and disproportionate nuclear response	Response through the combined use of EDTs will be effective and easy to tailor and implement	Continuing the course of action already taken is the most optimal way forward

EDTs and the strategic appeal of retaliation

Irrespective of the impact of EDTs, a decision maker may have a strong predilection that only in-kind nuclear response can inflict the desired psychological impact upon an adversary. The decision on whether the desired psychological effect could be achieved with proportionate or disproportionate nuclear response could also be made irrespectively of EDTs. For example, an in-kind - but disproportionate - response may be desired if a decision maker believes that an adversary expected a proportionate response, and it was ready to accept the cost. There are, however, some situations in which EDTs could make a difference. For example, in case of a proportionate nuclear retaliation, the offensive use of various EDTs could amplify the psychological effect of the nuclear retaliation. This might be a way to convince an adversary that it made a miscalculation without having to resort to disproportionate nuclear use.

Under certain circumstances, kinetic and non-kinetic EDT capabilities might provide an alternative to a nuclear retaliation. For example, a decision maker may perceive that a response leveraging the combination of AI-enabled cyber-attacks, counter-space actions, and non-nuclear precision strike could inflict sufficient damage on an adversary by disabling part of the adversary's nuclear forces, or other critical military and civilian infrastructure. An asymmetric response that leverages EDTs might also be preferable if the adversary's nuclear attack did not reach the threshold of a nuclear response.

EDTs and escalation risks

After first nuclear use, any course of action to decisively alter the cost/benefit calculation of an adversary would have a high escalatory potential. This would happen irrespective of whether a conflict is taking place under the shadow of EDTs. In such circumstances, eliminating nuclear risks would not be possible. The only achievable goal would be to minimise these risks.

While making a choice, a decision maker may consider which option creates the smallest risk of being misperceived as an all-out-nuclear strike. This would depend to a large extent on the remaining early warning and ISR capabilities of an adversary. If such systems are already heavily degraded, even non-nuclear long-range conventional strikes might be interpreted as part of a counter-force salvo. To some extent, the adversary's gaps in situational awareness might be filled with direct channels of communication. However, the ability to communicate does not necessarily mean that assurances of the lack of intent for conducting an all-out strike would be trusted.

What might also impact the decision maker's calculus is the leader's own confidence in predicting not only the primary but also the secondary effects of retaliation. Predicting the latter might be especially difficult in case of an asymmetric retaliation. As a result, unforeseen and undesired secondary effects may enrage an adversary to lash out with a large-scale nuclear counterattack. Given that, a decision maker may conclude that nuclear retaliation should be crafted in a tailored - and thus less risky - way.

EDTs and operational enablers and constraints

The combined use of EDTs could make some retaliatory options easier to implement. For example, leveraging EDTs could serve as an enabler of a nuclear retaliatory strike. Decision support tools compounded with AI-enabled ISR could speed up target selection and tracking. Counter-space, cyber, electromagnetic spectrum operations, and ISR capabilities could be also leveraged to enable nuclear-armed missiles or aircrafts to reach the targets by destroying, blinding, or avoiding adversary IAMDS. By strengthening a political leader's confidence that a limited, proportionate response was possible, EDTs may encourage the political and military leadership to choose this course of action. In contrast, if a decision maker would not have confidence in the ability to conduct a limited strike, a disproportionate response might be the only available nuclear option.

In some circumstances, leveraging EDTs may be selected as an alternative to in-kind response. Asymmetric response may be favourable if there is no viable option for a proportionate nuclear response and disproportionate nuclear response is not desired. This might also be the case if an EDT-enabled non-nuclear offensive attack can achieve military objectives with the least amount of destruction. The choice of asymmetric response would depend on whether EDT effects could be tailored to destroy, disrupt, or disable certain set of targets, including targets on the battlefield. It would also depend on how quickly non-nuclear, kinetic and non-kinetic strike options could be generated, and how quickly the effects of a strike would be visible to the adversary. In some circumstances, a prompt response might be desired as it may reduce the risk that an adversary would misjudge a delay in response as a signal of weakness - or take advantage of the delay to accomplish a *fait accompli* on the battlefield. For this purpose, more capable and automated big data analytics efforts can reduce the time and complexity of updating target databases and stockpiles of cyber exploits. Greater autonomy in both weapons platforms and C2 systems could also allow for more timely and complex coordinated operations that, for instance, complicate defensive measures by allowing multiple strike platforms to converge on a target from different attack vectors.

Decision about whether to expand the scope and intensity of initial limited attacks

An initial nuclear exchange, no matter how catastrophic, might not lead to the de-escalation or termination of a conflict. At least one side might be determined to continue fighting. In such circumstances, a decision maker might contemplate the risks and benefits of expanding the scope and intensity of its nuclear attacks. This could involve the option of limited nuclear strikes deep into the territory of a nuclear-armed adversary, especially if the threshold of attacking the adversary's homeland had not been crossed yet. The size of such an attack may depend on the specific actors involved, but it could involve attacks with dozens of nuclear explosives.

EDTs can contribute to the development of potential courses of action, provide insight into the potential for success and failure, and set the decision-making context by providing insight into adversary capabilities, intentions, and potential reactions. Technology could also help devise unconventional strategies which could involve nuclear use.

However, political, strategic, and military objectives are likely to dominate the decision-making process regardless of the technological context. Much may depend on how available choices are framed: is nuclear war the only alternative to total defeat? Could further nuclear use break the adversary's will to continue fighting? Is there domestic political and military pressure to punish the aggressor and teach future aggressors a lesson? Leaders may also face a choice between nuclear escalation and their personal and political survival, particularly in authoritarian regimes. Technology can contribute to how choices are understood and presented, but decision makers would have to surrender significant trust to technological systems to accept these recommendations uncritically.

EDTs and the decision-making context

As with all other scenarios, the situational assessment is an important element of the decision-making context. Decisions about expanding the scope of nuclear attacks may partly depend on whether the decision maker has accurate and reliable information about adversary intent and likely responses to escalation. If, after limited nuclear exchange, the combinations of EDT-enabled ISR and decision-support systems continue to function, a national leader could be better positioned to avoid mistakes and miscalculation.

The domestic political context would also have an impact on this decision. Public fear about the consequences of continuing the fight could create strong pressures to capitulate, but adversary intervention could also provoke a backlash and drive public opinion to push for an expansion of the conflict. EDTs that affect a decision maker's ability to deliberate provide multiple different ways public opinion could be manipulated in either direction.

At this decision point, it is even more important than before that the decision maker can assess damage and anticipate the consequences of different courses of action. After initial nuclear use on both sides, any further course of action would heavily depend on how much damage each side has taken, which systems still function, and how certain decision makers behave in all of these assessments. If the prior nuclear exchange damaged crucial elements of NC3 systems, early warning capabilities, communications, and ISR capabilities, the decision maker would not be able to make an informed decision and would not have confidence in its ability to execute the nuclear attack. In this sense, both the combined use of EDTs and the degradation in EDT-enabled systems could lead to a greater degree of uncertainty about the broader context of the conflict.

EDTs and decision-making choices

As with the previous decisions, the complex interactions of EDTs would have uncertain effects on the choice of whether to expand nuclear strikes to an adversary's homeland. As above, three basic considerations might come into play. First, whether the use of EDTs could provide an alternative to a nuclear strike in achieving strategic objectives. Second, whether the complex interactions of EDTs increase or decrease the chances of a successful strike against an adversary's homeland. Third, whether the combined use of EDTs makes the risks of further nuclear escalation more or less manageable.

The below table summarises the considerations that might have an effect on the decision to expand the scope and intensity of initial limited attacks.

EDTs and incentives to expand the scope and intensity of nuclear attacks	**Disincentives to expand the scope and intensity of nuclear attacks**
No alternative option to a nuclear strike against an adversary's homeland	The combined use of EDTs provides an alternative option
The interactions of various EDTs increase the chances for a successful strike	The interactions of various EDTs decrease the chances for a successful strike, especially a limited one
The combined use of EDTs makes the risks of further nuclear escalation more manageable	The combined use of EDTs makes the risks of further nuclear escalation less manageable

EDTs and the strategic appeal of larger-scale attacks

Being unable to defeat an adversary in a regional theatre, a decision maker may assess that the only way to end the conflict on favourable terms is to directly strike the adversary's homeland. There may be several rationales for doing so. Nuclear weapons may be the only military capability available to continue the fight after a costly conventional battle. They might be used like strategic bombing during the Second World War—to target adversary war-making capability, major military bases, adversary nuclear forces, etc. The logic of such an attack would be to even the playing field and degrade the adversary's ability to keep fighting. Such attacks could also dramatically raise the costs of continuing to fight. All alternative options, including large-scale cyber attacks and conventional strikes, might have already been tried and failed to turn the tide of war.

Using EDTs as an alternative to a nuclear strike would require from a decision maker to have a 'ace in the hole' kept specifically for such situation—a pre-planned option for a strategic non-nuclear attack sufficient to bring an adversary to their knees or to the negotiation table without risking all-out nuclear annihilation. This might include taking advantage of various EDTs to destroy or disrupt an adversary's critical military and civilian infrastructure to stir destruction and internal chaos. To execute such an option, a decision maker would have to have the confidence that the option could be effectively executed, in spite of the adversary's countermeasures; that it can achieve objectives in a timely manner; and that it will not create undesirable side effects.

EDTs and escalation dynamics

Contemplating a nuclear attack against an adversary's homeland, a decision maker would most likely be aware that such an action could invite nuclear retaliation. Depending on the scale and targets of such an attack, expanded operations could also result in major humanitarian and environmental consequences.

Could leveraging EDTs make such a decision easier by reducing the risks of an unlimited exchange? It seems that EDTs might, under some circumstances, decrease the risk that a limited strike against an adversary's homeland would be seen by an adversary as an all-out nuclear strike or a decapitating strike against the leadership. This would depend on an attacker's ability to leverage EDTs to conduct a limited strike, and also on the defender's ability to interpret this attack as such.

However, the combined use of EDTs could also increase the risk of uncontrolled escalation. If an attacker successfully employed different EDTs to undermine an adversary's situational awareness capabilities, damage assessment tools, and communication lines, a decision maker could panic and misunderstand a limited strike as an all-out decapitating strike. Conversely, EDTs might also provide the decision maker with misplaced confidence in their ability to control the consequences of a limited strike against an adversary's homeland. In such a case, a decision maker could greatly underestimate how an adversary might react in response to an attack on its homeland, especially if the attack led to many civilian casualties or undermined the defender's assured second-strike capability.

EDTs as operational constraints and enablers

If still available at this stage, certain EDTs could enable a limited nuclear strike against the adversary's homeland by targeted non-kinetic (cyber and counter-space) and kinetic (hypersonic missiles and uncrewed, remotely-piloted systems) attacks that aim to disrupt and destroy an adversary's air and missile defence capabilities and C2 nodes, as well as the early warning systems that could notify adversary decision makers of an incoming attack. The availability of these EDTs might make a decision maker more willing to expand the scope of conflict through limited nuclear strike, reducing the incentives for an all-out attack.

This option would, however, depend on the combination of EDTs that the attacker and the defender possess. If an adversary's IAMDS cannot be disrupted or destroyed, the chances of a limited strike against high-value targets might be radically diminished. The defender could also resort to other measures to defend against missile attacks. These could include pre-emptive attacks on adversary missile sites using conventional strike weapons as well as cyber and counter-space operations to prevent missiles from launching or interfere with their command and control systems. Such measures have been referred to as "left of launch" missile defence.[44]

Decision on whether to escalate to an all-out nuclear war

The final decision that could confront decision makers is whether to contemplate a very large-scale attack on an adversary, one that could involve hundreds of nuclear detonations on a range of targets. Just like in previous decisions, the decision to order an all-out nuclear strike would be driven by several non-technological considerations. First and foremost, a decision maker would have to consider the consequences of attacking: whether and how the adversary would retaliate, the moral costs, the humanitarian and environmental effects, the attacker's reputation, and alliance relationships. The attacker might also consider the impact on the post-war world and the attacker's political position in that world.

Despite the risks inherent to this decision, a decision maker might still decide to pursue a full-scale nuclear war to prevent further nuclear attacks, limit damage to oneself, and end the war. Beyond these purely strategic considerations, decision makers may also conclude that a full-scale attack was necessary to punish aggression. Allies and domestic publics may also demand a full-scale attack for any of the above reasons, or just to satisfy a desire for vengeance.

A full-scale nuclear attack could involve a campaign to destroy an adversary's ability to make war. The decision maker would decide to target the adversary's nuclear and other military forces, the transportation and other infrastructure necessary to keep fighting, and potentially critical industrial areas. This campaign could involve some effort to limit collateral damage and spare adversary leaders. Alternatively, a full-scale attack could target the adversary government, aiming to decapitate the adversary in the hope of limiting its ability to keep fighting. Alternatively, the decision maker could attack the adversary's economy and society, punishing civilians for the actions of their leaders. Decision makers could also opt for a combination of attacks. The common thread uniting these attacks is that each involves the erosion of prior constraints. No effort would be made to communicate restraint or preserve adversary agency. The logic of coercive diplomacy would give way to the logic of brute force.

In addition to political and military objectives, factors such as operational concerns and the potential risks of such attacks would also influence the decision maker. What if a decapitation attack fails? What if a counterforce campaign fails to limit damage to the attacker? What if the decision makers' own forces fail to perform or are targeted first? The decision to use large numbers of nuclear weapons is likely to be fraught - even absent the introduction of EDTs - and psychological factors could also shape decision making.[45]

EDTs and their impact on the context of escalating to an all-out nuclear war

Many of the contextual factors that would influence the decision to launch a full-scale nuclear attack are like the same that would influence other kinds of nuclear use decisions. For instance, EDTs could affect decision making by facilitating more accurate assessments of the external environment, or they could lead to an erroneous interpretation of enemy behaviour. If the military balance is highly favourable to one side, decision makers might be more, rather than less, tempted to try to end the war through one final large-scale nuclear attack.

EDTs would also play a role in sustaining a decision process after extensive attrition of the range of military capabilities. Since an initial nuclear exchange has already taken place, it is very likely that IAMDS, ISR capabilities, and even crucial elements of NC3 systems have already been degraded, and might therefore not be available. To the extent that EDTs enable resilience of critical systems, they could support deliberation and therefore allow for a more considered course of action.

Given the futility of previous efforts to end the fighting, however, even a considered decision-making process could result in significant nuclear escalation. Here, EDTs could reinforce a consensus in favour of a last-ditch effort to end the conflict with nuclear attacks. EDTs could incentivise a full-scale nuclear attack by convincing decision makers that the war can be terminated without the fear of enemy response. If cognitive closure, fatalism, and other psychological factors come to dominate decision making, as they might, EDTs could also play a role in either reinforcing or mitigating cognitive biases. EDTs could lead to false conclusions and reinforce prior misconceptions about adversary intent, as well as the strategic and tactical benefits of large-scale attacks.

If leaders hold out hope of a negotiated settlement or the surrender of adversary leaders, ISR and communication systems would contribute to ensuring the survival of the enemy government. On the other hand, if there is no expectation of a settlement, the primary mission of improved ISR systems is to clarify the range of options available to decision makers. This could either reinforce the rationale for a full-scale nuclear attack by revealing the possibility of a purely counterforce/damage limiting attack option; or weaken by revealing the size and survivability of adversary forces.

EDTs impact on the choices of a decision maker

EDTs could both increase or reduce the desirability of a full-scale nuclear attack depending on their effect on the advantages of attacking and the alternatives available to decision makers. There are three key considerations that could drive this decision. First, does the combined use of EDTs provide a viable alternative to full-scale nuclear use? Second, whether EDTs can increase or decrease the effectiveness of a full-scale nuclear attack. This question is highly dependent on the availability of specific EDTs. Third, unlike in the case of previous decision points, the last consideration is less about managing escalatory risks, and more about the survivability of nuclear forces.

The below table summarises the considerations that might affect the decision to launch a full-scale nuclear strike.

Incentives for nuclear restraint	**Incentives for full-scale escalation**
EDTs provide political, strategic, and military alternatives to full-scale nuclear use	EDTs cannot serve as a viable alternative to full-scale nuclear use
EDTs decrease the chances of a successful full-scale nuclear attack	EDTs facilitate better targeting of adversary nuclear forces
EDTs help bolster the survivability of nuclear forces and defences against a nuclear attack, disincentivising an all-out attack	EDT-enabled forces are exacerbating vulnerabilities and incentivise an all-out attack

EDTs and benefits of full-scale nuclear use

If a rational decision-making process does not break down, EDTs can affect full-scale use decisions through their effect on how decision makers understand the available courses of action and the strategic consequences of restraint.

If the adversary possesses nuclear forces that are likely to survive even a full-scale nuclear attack, the decision maker has no rational incentives to launch such a major attack because of the threat of nuclear retaliation. In this regard, if the remaining EDTs can bolster the survivability of nuclear forces, they act as a constraining factor in a decision maker's cost/benefit calculation. However, if EDTs exacerbate vulnerabilities in nuclear forces, a decision maker might rightly conclude that they provide an opportunity for decisive action.

In theory, EDT-enabled conventional forces and better targeting could provide attackers with the ability to pre-empt an adversary's forces with lower collateral damage. If a decision maker could destroy most of the adversary's remaining nuclear forces with a combination of penetrating adversary networks, conventional strikes, and effective defences, they may be able to carry out a disarming attack with fewer or even no nuclear weapons. For this scenario to succeed, the attacker would need to possess enough highly effective non-nuclear capabilities to degrade the adversary's entire nuclear arsenal. If states are unable to reconstitute these capabilities, they may find themselves with few alternatives to full-scale nuclear use. The paucity of alternatives may then reinforce feelings of desperation or the sense that preserving future military leverage requires acting now.

EDTs, operational enablers and constraints, and other risks

EDTs could increase the appeal of a full-scale strike by providing more reliable and precise data on the location of adversary weapons, thereby increasing confidence in the effects of a pre-emptive attack. Possessing technologies such as more sophisticated cyber weapons, IAMDS, and hypersonic nuclear weapons could further increase the appeal of a full-scale attack by improving the probability of success, limiting the adversary's ability to retaliate, and minimising collateral damage by reducing the number and destructiveness of nuclear weapons used in the attack.

As decision makers begin to contemplate all-out attacks, structural factors such as the military balance may have an effect on the role that EDTs play in the decision-making process. If the adversary's forces are relatively small, decision makers may conclude that quantum sensors for anti-submarine warfare, air-dropped sensors to detect the movements of mobile missiles, and remaining cyber exploits provide enough confidence in the potential success of a damage limitation campaign to authorise the attack. Even relatively high error rates in these systems might be acceptable in a moment of desperation because a low success rate still destroys a significant portion of the adversary's forces. Conversely, EDTs could reduce the appeal of a full-scale nuclear attack if modelling and simulation systems demonstrate that even a highly successful attack is unlikely to contribute to the enemy's military defeat or the destruction of its retaliatory forces.

Beyond the potential for the adversary to retaliate, escalation risks may play less of a role at this stage. However, EDTs could contribute to understanding the downside risks of a large-scale attack campaign. For instance, existing research suggests that the environmental consequences of a large-scale attack are heavily dependent on targeting choices and local weather conditions. Modelling these complex interactions has historically taken some time and effort.[46] Improved computation capabilities fused with real-time data on weather conditions gathered from autonomous ISR platforms and space-based systems could help optimise a large-scale nuclear attack campaign. Targets with the potential to generate significant fall-out could then be struck with conventional weapons.

CONCLUSIONS

This report was aimed at visualising how the complex interactions of EDTs might influence nuclear decision making in the 2025-2030 timeframe. The report has found that in an escalating conflict between nuclear powers, EDTs may not be the only factor influencing a decision maker's behaviour and generating complexity. There are many other considerations, such as cultural, political, and military-operational objectives that are likely to have a more decisive role. The impact of EDTs on the choices of leaders of nuclear weapon states cannot be analysed in isolation from the deliberate decision-making process that each nuclear power has in place and continues to improve with the changing technological context.

The overarching conclusion of this report is that the complex interactions of EDTs create potential risks and rewards for nuclear decision makers at every key nuclear decision point: the decision to signal nuclear resolve in a crisis, the decision to cross the nuclear threshold through limited nuclear use, the decision to respond to a limited nuclear attack, the decision to expand the scope and intensity of the conflict, and the decision to escalate to an all-out nuclear war. This echoes our earlier finding that every hypothesis about the disruptive effects of EDTs and multi-domain complexity generates a counter-hypothesis.[47]

The complex interactions of EDTs could positively or negatively impact both the context in which nuclear decisions are taken and the choice of the particular course of action. With regards to the context, certain combinations of EDTs could improve the decision maker's ability to make a more informed decision during a rapidly escalating crisis or conflict. In particular, autonomous intelligence and data collection platforms, advanced applications of AI and ML for decision support, and resilient space-based NC3 systems may decrease the pressure on decision makers to make hasty and premature nuclear decisions at each stage of a conflict. Conversely, in some circumstances, the benefits of such combinations of EDTs could be negated by the decision maker's overconfidence in the advice they provide and an adversary's countermeasures to exploit this overconfidence.

Different combinations of EDTs could impact a decision maker's choice of particular actions by influencing the calculation of benefits of nuclear restraint over resolve. For example, under some circumstances, leveraging EDTs could provide an alternative to nuclear first use, nuclear retaliation, or further escalation. Integrated use of AI-enabled cyber strikes, kinetic and non-kinetic counter-space attacks, and non-nuclear long-range precision strike might enable a decision maker to achieve the desired psychological effects and strategic goals without nuclear use. Also, the defensive combinations of EDTs could also enhance deterrence by denial, decreasing the incentives for nuclear use. A high-density integrated air and missile defence network, that takes advantage of AI-enabled ISR data and swarms of interceptors, could convince an attacker that a very limited nuclear attack would fail. Still, in other circumstances, different combinations of EDTs might make the decision maker more confident in the ability to resort to nuclear use to achieve objectives while minimising the escalation risks.

The examination of the impact of multiple EDTs reveals that the implications of the same combinations of EDTs might be different at different decision points. For example, the same combination of technologies that might create additional incentives for using nuclear weapons first, could encourage a decision maker to pursue a more restrained option in response to a nuclear use by an adversary. In particular, the combination of AI-enabled ISR capabilities to locate targets, hypersonic weapon systems armed with low-yield warheads, and counter-space weapons and cyber tools to disrupt an adversary's defences and C2 systems could create incentives for a decision maker to strike early in a conflict. At the same time, it may provide a decision maker with an option of a more tailored - and less escalatory - way to respond to a nuclear use by an adversary.

The report also highlights that the relevance of specific combinations of EDTs changes from one decision point to another. For instance, the longer the conflict lasts, the more important it is for the decision maker to have confidence in its ability to execute nuclear operations. The interaction of a decision maker with specific combinations of EDTs, for example those that have an impact on situational assessment and decision support, is also likely to be shaped by the decision maker's experience in the earlier phases of the conflict. The use of specific combinations of EDTs at the early decision points might exclude their use in later stages. This might be because of the one-time nature of certain capabilities, or their attrition over the course of high-intensity war. Another source of complexity is that certain combinations of EDTs might become irrelevant because of one missing element in the entire combination. For instance, EDT-enabled decision support tools might become irrelevant without reliable ISR and leveraging the benefits of an AI-enabled network of sensors would not be possible if the decision support tools are ineffective.

RECOMMENDATIONS

Decision makers should seek to understand the limitations and potential consequences, intended and unintended, of the more widespread adoption of EDTs. Given the potential for significant risks to emerge, decision makers should also seek opportunities for risk reduction. Yet a comprehensive risk reduction agenda is likely to remain elusive for some time given the "emerging" character of disruptive technologies. Historically, states have adopted comprehensive arms control measures only after disruptive technologies have emerged and were widely diffused. There is nevertheless much to do to lay the conceptual foundation for risk reduction measures. Such efforts should cover a number of unilateral and cooperative measures.

Unilateral measures

There are a number of concrete unilateral measures that each nuclear weapon state can take to identify opportunities for risk management associated with the impact of the complex interactions of EDTs on nuclear decision making. The primary benefit of unilateral steps is that any nuclear decision maker can implement these tools regardless of the security environment or the adversaries' willingness to negotiate. These measures could extend to improved risk assessments, strategic and operational planning, exercises, and efforts at improving resilience.

First, any risk reduction efforts associated with the complex interactions of EDTs has to start with a better understanding of the risks. These efforts should aim to build a common understanding of the risks that transcends professional, bureaucratic, and national boundaries. To do so, while incorporating EDTs into their military capabilities and strategic postures, decision makers should concentrate not only on the 'good' but also 'the bad and the ugly.' This includes seeking better understanding on how EDTs could impact nuclear decision making during all phases of conflict. Such 'thinking about the unthinkable' is necessary because hesitation to speak in a frank but informed way about escalation dynamics can potentially increase the risks of unwanted nuclear escalation. This could include wargames undertaken at the official, including inter-governmental, and "track 1.5" level, that is with the involvement of governmental and non-governmental experts. The growing interest of different governments in net assessment efforts could also provide opportunities to better understand the risks posed by EDTs.[48]

Second, governments should incorporate the assessment of the consequences of EDTs for nuclear decision making into the periodic reviews of nuclear deterrence postures. These reviews should seek to identify the implications of EDTs for nuclear deterrence capabilities and escalation management. This includes identifying the combinations of EDTs that have high potential to create unwanted risks; the combinations that could be leveraged to reduce these risks; but also the combinations that could contribute to reducing the reliance on nuclear weapons in a conflict by, for example, providing an alternative to a nuclear use. The results of the reviews could help to create oversight and a capability planning process that is tailored to mitigating the negative consequences of EDTs. The reviews could also lead to changes in operational planning to minimize unwanted risks.

Third, the governments should incorporate EDTs into nuclear exercises. This could include regular nuclear exercises that are primarily aimed at exploring the impact of different combinations of EDTs on nuclear decision making and nuclear operations in different scenarios of crisis and conflict. Wargaming, table-top-exercises (TTX), modeling and simulations should also account for nuclear escalation scenarios under technological complexity. These tools could not only improve understanding of EDTs, but they could also inform arms control negotiations by identifying the most destabilizing uses of new technologies that nuclear powers might decide to limit through cooperative mechanisms.

Fourth, governments should strive for resilience in critical elements of nuclear decision making, including the ability to sustain decision-making processes, consult with allies, gather information, carry out critical missions, ensure the survivability of deterrent forces, and prevent unauthorized actions. Building resilience is a critical step to reduce unwanted risks and patch up vulnerabilities that could invite adversary attacks in a crisis or conflict.

While all of the above measures could contribute to risk reduction by providing a better understanding of the dangers of technological complexity and helping to raise awareness about the pathways to unintended escalation, they could also contribute to reducing risks by strengthening deterrence. It has been a longstanding position of most nuclear powers that maintaining a credible deterrence posture is an important element of the strategy to reduce first strike incentives and adversary adventurism.

Cooperative measures

The unilateral steps aimed at better understanding and mitigating risks associated with EDTs could also create conditions for cooperative risks reduction measures. Efforts by nuclear possessors to do their 'homework' on understanding risks associated with EDTs could reveal opportunities for bilateral and multilateral risk reduction efforts.

Past efforts at nuclear risk reduction suggest that there are several potentially useful models for cooperative efforts to manage the risks posed by EDTs. These include political-doctrinal measures, force reductions and non-proliferation efforts, operational measures, and confidence and security-building measures. Each involves different tradeoffs. For instance, while legally-binding treaties are difficult and slow to negotiate, they provide significant payoff in terms of enforceable and verifiable obligations. Conversely, political commitments and confidence and security-building measures are more flexible and easier to implement, but compliance is usually not enforceable and many violations happen without consequences.

Another option is for states to engage in an open-ended exploration of a particular problem through a structured dialogue. One such effort in the nuclear domain is the P5 process of recognized nuclear weapons states, which has already produced a working paper on strategic risk reduction.[49] The P5 effort could be broadened to incorporate discussions on the consequences of EDTs and also include other nuclear possessors. Different efforts may be undertaken through bilateral channels, such as the U.S.-Russia Strategic Stability Dialogue or future efforts between the United States and China. However, given the competitive nature of great power relations, it is going to take a long-term political commitment to transform these discussions into serious risk reduction obligations. With that in mind, decision makers could also support civil society and scholarly efforts to develop conceptual tools for risk reduction.

NOTES

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[2] Much of this discussion draws on a recent review of the literature undertaken by the authors and their colleagues. See Brad Roberts, *Emerging and Disruptive Technologies, Multi-domain Complexity, and Strategic Stability: A Review and Assessment of the Literature* (Livermore, CA: Center for Global Security Research, Lawrence Livermore National Laboratory, 2021), https://cgsr.llnl.gov/content/assets/docs/EDT_ST2_BHR_2021.3.16.pdf and Jacek Durkalec et al, *Multi-domain Complexity and Strategic Stability in Peacetime, Crisis, and War,* Annotated Bibliography, Center for Global Security Research, Livermore, California, February 2021, https://www.europeanleadershipnetwork.org/report/multi-domain-complexity-and-strategic-stability-in-peacetime-crisis-and-war-annotated-bibliography/

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