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RESEARCH ARTICLE

Reflections on the Evolution of Conflict Early Warning

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Conflict early warning is supposed to identify and trigger actions to reduce the onset, duration, intensity, and effects of multiple forms of political violence. While the commitment of nations to broader conflict prevention was not universally shared in the twentieth century, the concept of conflict prevention – and by extension, conflict early warning – has acquired salience in international relations over the last 30 years. This growing engagement, coupled with advances in computing, has triggered increased investment in enhanced early warning mechanisms with increasingly sophisticated temporal and spatial dimensions. Yet, the practical operationalization of conflict prevention and conflict early warning lags behind its theoretical development for several reasons. These include, *inter alia,* limitations in early warning assessments; the limited availability, coverage, quality and verifiability of real-time data; complex modelling challenges emerging from endogeneity inherent in conflict processes; and, not least, an inherent lack of political will among relevant actors to act upon robust and compelling evidence of heightened risks of organized violence. The latter is the core of the so-called 'warning-response' gap. Despite these challenges, investments in advanced data collection and analysis techniques including machine learning, natural language processing and artificial intelligence are influencing the practice of early warning and response. This article offers a descriptive review of the form and function of conflict early warning systems over the past four decades. In the process, it provides insight into why many of these systems have yet to live up to expectations.

Introduction

Conflict early warning is first and foremost intended to identify and trigger action to reduce the onset, duration, intensity, and effects of multiple forms of political violence from communal violence to outright war. The desire to deter collective violence is not always shared by everyone: certain elites and armed groups may be determined to sustain and prolong armed conflict (Stedman 1997; Walter 2002; Greenhill and Major 2006). Yet the avoidance of mass fatalities, large-scale displacement and devastating consequences for civilians is regarded as desirable by the international community on moral, legal, humanitarian, political, and economic grounds (Gates et al. 2016; UNU CPR 2017; Our World in Data 2021). While today widely accepted in principle, the commitment of states to conflict prevention in practice was

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intermittent in the twentieth century, especially during the Cold War (Lund 1996: pp. 3–4). However, since the 1990s, the concept of conflict prevention – and, by extension, conflict early warning — has acquired salience in international affairs (FEWER 1999).

At least three seminal publications influenced the conflict prevention and conflict early warning agenda. These include the United Nations Secretary General (UNSG) Boutros-Boutros Ghali's *An Agenda for Peace* report (1992); the Carnegie Commission on Preventing Deadly Conflict (1997); and UNSG Kofi Annan's *Prevention of Armed Conflict* report (2001). Throughout the 1990s and 2000s, conflict prevention concepts, terminology, and directives infused the declarations and statements of state, intergovernmental, and regional organizations as well as UN plans, communiqués, and mission mandates. The growing engagement with conflict prevention triggered increased investment in enhanced early warning. For example, multiple continental and regional early warning mechanisms were set up in Africa during these two decades, including: the Economic Community of West African States (ECOWAS) Warning and Response Network (ECOWARN) established from the 1999 Protocol Relating to the Mechanism for Conflict Prevention, Management, Resolution, Peacekeeping and Security (ECOWAS 1999; Odobo et al. 2017); the African Union (AU) Continental Early Warning System (CEWS) (AU 2006); the Intergovernmental Authority on Development (IGAD) Conflict Early Warning and Response Mechanism (CEWARN) established in 2002 (IGAD 2002; Goldsmith 2020); and the Common Market for Eastern and Southern Africa (COMESA) Early Warning System (COMWARN) (Porto 2013). Yet, the operationalization of both conflict prevention and conflict early warning lagged behind its theoretical development. Reflecting on almost two decades of intellectual foment, Lund argued in 2008 that it was likely an idea whose time had come and gone (Lund 2008: p. 287). While premature, Lund's prognosis reflected a wider sense of frustration with the lack of genuine support for prevention.

Notwithstanding the many political constraints on conflict prevention and early warning, the agenda has continued to grow. Over the past 15 years it has widened in the UN to incorporate normative arguments around states' responsibility to protect (R2P) civilians and non-combatants from specific types of political violence and atrocities, that is, war crimes, crimes against humanity, ethnic cleansing, and genocide (ICISS 2001; Willmont 2017). A milestone occurred with the incorporation of the R2P language into the UN Extraordinary Summit outcome document in 2005 (UN 2005). Indeed, 'enhanced early warning' is a key feature of the R2P agenda, as paragraph 138 of the Outcome document calls on member states to 'support the United Nations in establishing an early warning capability' for preventing mass atrocities (UN 2005: p. 30). External actors subsequently deployed this specific language to justify international military intervention in the Libyan civil war in 2011 (Welsh 2011; Bellamy 2011; Kuperman 2013; Doyle 2016) and R2P language later animated calls for international action in countries such as Syria and Myanmar (Bellamy 2014; Trihartono 2018; Ibrahim 2018). The UN Human Rights Up Front (HRUF) initiative also sought to bolster the focus on conflict prevention. By 2017, UN Secretary General António Guterres had made conflict prevention a centrepiece of his mandate, including calling for more robust early warning mechanisms across the UN system (Strauss 2018; Paddon Rhoads 2019). And, in the 2021 report *Our Common Agenda*, the Secretary General again advocated leveraging new technologies and machine learning capabilities to improve early warning (UN 2021). Among the key proposals addressing the 12 commitments in the report, the third proposal, 'Promote Peace and prevent conflicts', advocated a 'new agenda for peace' that would, inter alia: 'Strengthen international foresight; invest in prevention and peacebuilding; and support regional prevention'

(UN 2021: pp. 6, 59–61). These are all clear action items linked explicitly to enhanced technical early warning and prevention.

Even so, there is a noticeable gap between the rising ambition and concrete outcomes of conflict early warning. The increased investment in analytical tools and super-charged methods to anticipate the risks of organized political violence is seldom matched by concomitant political will and practical action (Hegre et al. 2017). Systematic conflict forecasting is not new and is deeply rooted in the systematic study of peace and conflict (Choucri 1974; De Mesquita et al. 1985; Gurr and Lichbach 1986). This article offers a descriptive review of the form and function of conflict early warning systems (EWS) over the past four decades. In the process, it provides insight into why it has yet to live up to the many expectations laid upon it.

Great expectations of early warning systems

An underlying assumption and motivation of conflict early warning systems is that enhanced *prediction* and *forecasting* can better inform decision-making, reduce risk, and trigger more robust prevention and response measures from international actors. These responses consist of a series of discrete actions made by international actors tasked with maintaining peace and security, including the decision-makers of individual states, regional organizations with relevant mandates, and the UN system. A contemporary snapshot includes conflict modelling and political instability forecasting tools developed by and for multiple audiences including the European Union External Action Service (EEAS), United States (US) Government, intergovernmental and regional organizations in Africa including the African Union (AU), Economic Community of West African States (ECOWAS), the Intergovernmental Authority on Development (IGAD), the Southern African Development Community (SADC), and various UN entities, as well as the growth in both closed intelligence and open-source event data sets and modelling tools housed within non-governmental organizations and academia such as the United States Holocaust Memorial Museum (USHMM) Early Warning Project, the Integrated Crisis Early Warning System (ICEWS), the Armed Conflict Location and Event Data Project (ACLED), the University of Uppsala's Conflict Data Program (UCDP), and the Violence Early-Warning System (ViEWS) discussed later in the article. Yet, efforts to both anticipate and respond to most outbreaks of collective violence have routinely performed more poorly than expected. This often comes down to, among other things, limitations in early warning assessments, the limited availability, quality, and verifiability of real-time data, and, not least, the modelling challenges emerging from endogeneity inherent in complex conflict processes. These early warning challenges are exacerbated by a small N (number of cases that can be studied), the problem of too many independent variables, and policy-maker complaints about the over-predictive nature of extant early warning models.

The widely acknowledged warning-response gap, first isolated over two decades ago by George and Holl (1997: pp. 9–11), is a crucial missing link between early warning and preventive action. It is also a consequence of limited political willingness to take action, even when relevant decision-makers are presented with rigorous and compelling evidence of heightened risks of organized violence. The literature on preventive action is rife with alleged missed opportunities for political will to respond (Zartman 2005; Piiparinen 2006; Meyer et al. 2010). The limited capacity of early warning systems to trigger action is well known, with policy-makers keen to leverage early warning products that reduce risk in their decision-making processes (Power 2013; Goldsmith et al. 2013; Luck 2018; African Task Force on the Prevention of Mass Atrocities 2016). It is instructive to note here the classic tension between theory and practice (George 1993), with comparatively recent International Relations scholarship seeking to articulate

what it is that practitioners require from theories and theorists (Avey and Desch 2014). Notwithstanding these structural constraints, considerable investment has gone into elaborating ever more sophisticated systems that assemble high-resolution monitoring, communication, and response (UN Office for Disaster Risk Reduction 2009).

Conflict early warning systems are a comparatively novel idea. Yet contemporary processes and platforms can be linked directly to a longer history of systems, methods and tools devised for minimizing risk and managing uncertainty in international affairs. Since the eighteenth century, Prussian Kriegsspiel (Livermore 1879) analysts have applied a combination of increasingly sophisticated wargames (Morgan 1991), risk analysis, statistical modelling, and what-if counterfactuals to gauge the risk of conflict. Contemporary approaches such as forecasting and prediction, simulations, red teams, agent- and evidence-based modelling, role-play, and table-top and computer simulations that leverage big data and machine learning draw on over a century of experimentation (Bhavnani and Sylvan 2017; Colaresi and Mahmood 2017; Zenko 2015; Abbass et al. 2011; US Army 2015).

However, starting in the 1980s, a constellation of governments, private companies, and international organizations ramped up their engagement with prediction and forecasting tools to assess a range of crises, including in relation to nuclear deterrence, armed conflict, and mass atrocities (see **Table 1**). Prediction entails the assignment of probability distributions to realized or unrealized outcomes. Forecasting entails predictions about unrealized outcomes based on model estimates from realized data (information about tomorrow based on information about what happened today). These methods also incorporate specific statistical techniques that are debated among subjectivist (Bayesian) and objectivist (Frequentist) approaches to statistical probability (Freedman et al. 2010: pp. 4–6; Craig et al. 2001). So, early warning systems typically encompass systematic approaches to providing regular forecasts for conflict-related environments. They have also undergone theoretical and methodological improvement over time (Hegre et al. 2017; Choucri 1974; De Mesquita et al. 1985; Gurr and Lichbach 1986).

Conflict early warning has undergone significant transformation over the past thirty years (FEWER 1999). The **first generation** of early warning (roughly 1995–2000) was centralized, predictive, and focused on supporting more robust decision-making among elite actors. A **second generation** (approximately 2000–2005) was more decentralized, qualitative, and oriented toward proposing recommendations for action. A **third generation** (broadly between 2005–2015) was hyper-localized, drew on both structured and unstructured data, and sought to harness community-based methods (Macherera and Chimbari 2016). The **fourth generation** (generally from 2015–2020) is quantitative, applying multi-spatial layers ranging from satellite-based remote sensing and social media to shallow machine learning that leverages open and administrative datasets (Letouzé et al. 2013: p. 6.). There are signs emerging of a **fifth generation** that promises to overcome the warning-response gap, one that applies deep machine learning and artificial intelligence (AI) to generate increasingly parsimonious assessments that are, crucially, then matched to a range of possible real-time decision options elucidating their inherent risks and payoffs. An example of this fifth generation can be found in American analytics firm Palantir's notional demonstration of its Gotham operating system (Palantir 2021). The proprietary software is applied to a US-China conflict scenario over the Taiwan Strait, culminating with the analysis of early warning data matched to ranked decision options for elite-level decision makers in a real-time crisis environment. US Defense is heavily invested in machine learning systems to model future conflicts globally, as well as to understand what types of US policy actions could lead to unexpected escalation by potential adversaries (Stone 2021). This

Table 1: Preliminary comparison of early warning systems and datasets.

	Functions	Organization	Institution and outputs
Armed Conflict Location & Event Data Project (ACLED)	ACLED maintains a dedicated Early Warning Research Hub allowing 'users to track a variety of different risk factors, across a range of contexts, in a way that meets their distinct needs'.	Collects real-time data from news feeds on the locations, dates, actors, fatalities, and types of all reported political violence and protest events across Africa, the Middle East, Latin America and the Caribbean, East Asia, South Asia, Southeast Asia, Central Asia and the Caucasus, Europe, and the United States.	Registered non-profit organization with 501(c)(3) status in the United States. Financial support from the Bureau of Conflict and Stabilization Operations at the US Department of State, the Dutch Ministry of Foreign Affairs, the German Federal Foreign Office, the Tableau Foundation, the International Organization for Migration, and The University of Texas at Austin.
Integrated Crisis Early Warning System (ICEWS)	Comprehensive automated system to monitor, assess and forecast national and subnational crisis (e.g., conflict, ethnic/religious violence, rebellion/insurgency)	Mixed method approach using 100 data sources and 250 newsfeeds parsed using Jabari technology and BBN Serif NLP technology. Includes iData (who did what to whom and when), iTrace (news mining), iCast (forecasting) and iSENT (sentiment). Uses a CAMEO ontology.	DARPA and the Office of Naval Research (2007 start) have developed a series of component tools and focused on 250 countries/territories. Currently maintained by Lockheed Martin.
Continental Early Warning System (CEWS)	Intended to anticipate and prevent conflict and provide timely information according to specific metrics	Observation and monitoring unit collects data and analysis and regional units linked to 'SitRoom'	African Union with MoU connecting Regional Economic Communities such as SADC, ECOWAS, (daily news, reports, flash reports and updates). SitRoom includes one coordinator, two communications assistants and ten assistants.
Political Instability Task Force (PITF) (Formerly known as the State Failure Task Force)	Seeks to measure the factors that lead to atrocities against non-combatant populations.	The dataset covers four state failure events: revolutionary wars, ethnic wars, adverse regime changes, and genocides and politicides. Ten variables are assessed based on their magnitude and the data is manually coded.	Center for International Development and Conflict Management (CIDCM), University of Maryland.

(Contd.)

	Functions	Organization	Institution and outputs
EC/EU Conflict Early Warning System (EWS) and GCRI	Assesses structural underlying risks for violent conflict (civil war, subnational conflicts, interstate conflict)	EC EWS includes the Global Conflict Risk Index (developed by ECJRC) and qualitative input from EU staff and country experts. The GRCI consists of a regression model and a composite model based on 24 variables from 14 different datasets. It generates a list of intensity of risk by country.	EU – External Action Service (EEAS) with European Commission
INFORM Risk, INFORM Severity and INFORM Warning	Provides risk assessment for humanitarian crises and disasters, a review of severity and issues warning globally to enhance preparedness, early warning and early action.	INFORM addresses several dimensions of risk related to hazard, exposure, vulnerability, and coping capacity.	A collaboration of the Inter-Agency Standing Committee Reference Group on Risk, Early Warning and Preparedness and the European Commission. Output: dataset, dashboard, country profiles, reports
ViEWS	Tracks four types of political violence including state-non-state actors, between nonstate actors, violence against civilians, and forced displacement.	Applies a blended approach including Bayesian and regression methods to generate early warnings for specific actors across geographic areas, one month in advance. Geographically focused on Africa.	Uppsala Conflict Data Program (UCDP), Department of Peace and Conflict Research, Uppsala University, Sweden. Cost is approximately Euro 600,000 a year.
EU-LISTCO (Nygärd et al. 2019)	Identifies risks in Europe in order to assess the EU's preparedness and resilience in responding to governance breakdowns.	Applies a blended approach to track multiple types of conflict and governance breakdown. Geographically focused on four areas (EU and selected sites such as Mali, Georgia, and Ukraine). Timeframe is limited to 1989 and 2017.	Project funded by the EU's Horizon 2020 Research and Innovation Program. Output: reports, publications, infographics, newsletters. Consortium of 14 universities and cost of roughly EUR 5 million (2018-2021).
Situational Awareness Geospatial Enterprise (SAGE) (Duursma and Karlsrud 2019)	An incident and event database developed in 2018 used to identify trends and indicators for early warning.	SAGE features an incident monitoring database used by UN military, police and civilians in UN peace operations. Since structured data is stored and categorized, it can be analyzed using machine learning.	United Nations Department of Peacekeeping Operations (UN DPKO).

(Contd.)

	Functions	Organization	Institution and outputs
Conflict Early Warning and Response Mechanism (CEWARN)	Assesses regional situations that could potentially lead to violence, develops case scenarios, shares analyses and prepares response options.	CEWARN divides incidents into four categories: armed clashes, raids, protest demonstrations, and other crimes. The mechanism consists of 50 indicators from open sources and SitRoom reports.	IGAD (Intergovernmental Authority on Development) member countries: Djibouti, Ethiopia, Kenya, Somalia, Uganda, Sudan and Eritrea. Cost was reportedly USD1.4 million per year.
Early Warning Project	Applies qualitative and quantitative forecasting methods to identify countries where risks of mass atrocities are high.	An annual statistical risk assessment of 160 countries based on assessing historical episodes (1945-present) and training a model (logistic regression with elastic-net regularization) of roughly 20 variables to predict onset risks.	Joint initiative of the Simon-Skjodt Center for the Prevention of Genocide at the US Holocaust Memorial Museum (USHMM) and Dartmouth College.
Atrocity Forecasting Project	Deploys multiple quantitative forecasting models to improve insight on causes of political instability and conflict leading to mass atrocities and genocide.	The Atrocity Forecasting Project applies machine learning-based forecasting techniques based on over 200 incidents recorded between 1946-2017.	Based in the Australian National University, the initiative issues periodic updates on risks for a specific interval (2015-20). The project also hosts periodic events.
The Sentinel Project EWS	Focuses on genocide prevention, though alert functions are still in development	Draws on open sources, including social media to monitor potential genocidal events in selected sites – i.e., Myanmar, Central African Republic, Democratic Republic of Congo, Iraq, Kenya, South Sudan and Uganda. Currently developing a database that will facilitate automated data collection from open sources.	Based in Canada and outputs include reports and visualizations. No dedicated staff or budget in 2020.

linking of advanced early warning products to actionable decision options for both internal and external actors constitutes arguably the final step in mature early warning and response systems, but currently remains the proprietary domain of well-resourced state defense and intelligence apparatuses.

Today, most conventional early warning systems involve a combination of tactical, strategic, and operational *analysis*, *alerting* and *action* through mandated institutions. Some experts distinguish between 'last mile' EWS (focused on threats and top down) and 'first mile' EWS (people-centred and bottom-up). Most of the literature is focused on the former. These are typically systems based on a wide range of metrics, managed by large agencies made up of technicians and specialists, include standard operating procedures, and mobilize a host of technologies and metrics. There is a much slimmer engagement with community-centric and participatory EWS that are more flexible, ad-hoc, and personal. Other terms include 'people-centred' EWS, 'community early warning systems', citizen-centred EWS, community-centric EWS, community-based EWS, and participatory EWS (Marchezini et al. 2018; Macherera and Chimbari 2016). For some organizations such as the Organization for Security and Co-operation in Europe (OSCE) there is a neat distinction between analysis and alerting on the one side, and action, including conflict mediation and resolution, on the other. For others, such as the African Union (AU) or Economic Community of West African States (ECOWAS) the functions are, at least theoretically, more seamlessly integrated. The basic assumption implicit in most early warning systems is that the underlying risks associated with crisis and conflict can be meaningfully tracked, analysed, communicated to, and synthesized by, decision-makers and ultimately used to formulate action-oriented proposals (Willmont 2017). As previously detailed, critics note that even where they may generate urgent recommendations for action, they rarely precipitate adequate responses due to political resistance (Zenko and Friedman 2011; Luck 2018). This does not necessarily mean that the early warning monitoring systems are faulty, but rather that there is insufficient will to act on their findings.

There is no single monolithic archetype for conflict early warning. A decade-old review by Barton et al. (2008) detected over 30 separate systems and datasets addressing issues of violent conflict, state failure, genocide, mass atrocities, humanitarian emergencies related to natural disasters, and other threats to political stability. Some conflict early warning systems are overseen by governments and international/regional organizations while others are administered by think tanks, universities, and private actors. Multiple studies conducted by scholars and representatives of international organizations have explored various types of early warning platforms (Wulf and Debiel 2009). Additional studies suggest that there are likely many more (OECD 2009). Early private entrants into the international early warning consulting space, such as Virtual Research Associates (VRA), produced bespoke software for modelling conflict for a range of regional actors in Africa (Bond 2020). An array of global consulting firms have also entered the early warning space including Stratfor and Eurasia, with a focus primarily on risk assessments, scenario-based forecasting, red teams, and 'what if' counterfactuals (Weber 1996: pp. 268–288; Zenko 2015). More recent groups such as GDELT, IntelHub, or Luminae Group, to name but a few, have been developing interactive visualization platforms to allow users to interact with real-time economic, political, sentiment, and social media metrics.

Predictably, there are also a wide range of methodological approaches used to conduct conflict early warning (Defontaine 2019). Some apply correlation and regression models focused on demonstrating causal pathways for conflict by testing the strength of specific independent variables (for example, the USHMM Early Warning Project). There are also sequential models that filter out selected risks that accelerate crises over a

multi-year time horizon. Another approach involves conjectural modelling, an approach often employed in the banking sector that examines a range of escalation scenarios and thresholds for conflict onset, as well as possible responses that identify opportunities for early intervention. Several characteristics are positively associated with effective early warning data collection, collation, and analysis. These include: standardized, regular, and timely data feeds; the use of a wide range of datasets; shared problem definition and recognition of options for response; and the harnessing of local-level analytical capacities. Datasets can include data on demographics (age, gender, socio-economic structure, population distribution, ethnicity), education (drop-out rates, completion rates, illiteracy), and security (violent/non-violent incidents, participation of military, trust in security institutions). Also typically included is data on socio-economic characteristics (poverty, inequality, food security, access to services), macroeconomics (inflation, unemployment, cost of food basket), and energy sector information (composition of energy matrix, electricity prices, fuel costs). Information is usually pulled from a host of sources. These include administrative data, media and incident reporting information, open and closed sources, and a range of audio-visual sources. Data can be generated from interviews, focus groups, Delphi surveys, and other evergreen sources.

There is also a growing reliance on the use of a wide range of field-based networks, the use of open-source data, and the application of mixed methods including both physical incident reporting as well as social media monitoring. With respect to action, there is widespread consensus that a two-way connection between warning and response is essential, including monitoring the outcomes of interventions, at the subnational and hyper-local scale as well (Macherera and Chimbari 2016; Marchezini et al. 2018). Indeed, the traditional country-level unit-of-analysis and yearly aggregated data focus common in international relations and conflict studies has given way to high resolution event-level data enabling stronger comparisons and trend analyses over much shorter time horizons. The Satellite Sentinel Project is an early example of an open-source project in which real-time satellite imagery captured data on village-level physical violence in Sudan (Satellite Sentinel Project 2012).

Despite this explosion in event-level data, there is ongoing debate among scholars and practitioners regarding the veracity, quality, coverage, and coding of event-data, for example in relation to the politics of body counts (Krause 2018), particularly emerging from datasets that rely primarily on news wires and journalistic or word-of-mouth coverage in conflict environments (Krause 2016, see pp. 116–118 in particular for discussion of data discrepancies; Dawkins 2019). In a recent empirical study of ACLED and UCDP-GED conflict data generation in the South Sudanese Civil War, Dawkins asks provocatively if it is even possible to 'build better cross-national fatality measures given the biases inherent in the data-generation process' (Dawkins 2021: p. 1098).

It is worth noting that while 'early warning' and 'risk assessments' are often treated as synonyms, they are two distinct processes. Very generally, early warning combines both qualitative measures with some form of statistical modelling. The focus is usually on identifying short-term triggers with the intention of providing timely and sufficient information. This includes: widening cleavages among political elites; changes in the military capacity of oppositional forces; highly contested upcoming elections; and the expansion of security forces. Early warning models also often track other 'peace-centric' factors that may arrest or de-escalate volatile dynamics, such as the presence and strengthening of peacekeeping forces to reinforce stability, temporary cease-fires, and other short or mid-term policies that aim to create a space for political negotiation and eventual conflict termination or transformation. Few early warning systems fully clarify

their methodology, how information is gathered, or the sources being used. Approaches tend to include time-series analysis, vector auto regressions and Bayesian modelling. Examples of variables for early warning include: increased hate in the media, public rallies, elections, public commemorations, changes in government leadership, increased repression, physical separation of vulnerable groups, arms transfers, opposition capacity increase, deployment of security, armed conflict and targeting of civilians, and even natural disasters. By contrast, risk assessments tend to be longer-range quantitative assessments. The focus is ordinarily on identifying the structural conditions of conflict violence onset, escalation, and duration. Examples of such variables include: political regime type (e.g., autocratic, democratic); prior history of political instability; the degree of integration into the global economy; and levels of state-led discrimination, etc.. They tend to be predictive (and not causal) models concerned with identifying probability and correlations. Ensemble forecasting is another form of risk assessment that assesses averages across models. Common variables include: history of prior atrocities, regime type, political stability, history of conflict, neighborhood effects, and economic factors (Krain 1997; Harff 2003; Goldsmith et al. 2013; Brandt et al. 2014; Chadefaux 2017; D'Orazio 2020).

Early warning and risk assessment methodologies are steadily evolving. Consider the EU Conflict Early Warning System, or iTrack. The iTrack mechanism combines imagery intelligence with geospatial insight and a Global Conflict Risk Index to generate real-time analytics. The index features 25 metrics (grouped in security, social, economic, political, and environmental categories) with most information collected from open sources (Berglund 2017). Another promising early warning platform is ViEWS, launched in 2018 by UCDP. It applies model ensembles, out-of-sample evaluation and Bayesian model averaging to forecast 36 months into the future across three types of organized violence in Africa (Hegre et al. 2019). Today, most early warning systems involve an element of forecasting based on a wide range of data. Owing to delays in data processing and the imperative of speeding up analysis of fast-moving situations, there is growing interest in 'nowcasting' methodologies. Nowcasting was originally designed to generate economic data based on limited and incomplete datasets (Thorsrud 2016). By definition, nowcasting requires a trade-off between timeliness and data quality. It also suffers from some limitations because not all contemporaneous data is necessarily available at the right time (the 'missing data' problem). As such, aggregates are constructed by observing disaggregates. There are often measurement error problems because observed data may be subject to later changes. There are also changing database problems because different components of the data may be unavailable for certain periods. Moreover, 'break problems' can also threaten their accuracy (Castle et al. 2009).

Prediction is widely applied in early warning systems and risk assessment tools. Predictive capabilities are improving due to advances in computationally intensive methods to collect and analyze data. For example, as the cases of iTrack and ViEWS show, there is growing use of automated event-coded data. Such approaches are often used to measure changes in regimes and leadership, the dynamics of subnational organized violence, the characteristics of social movements, and other phenomena. Most methods are based on granular temporal and geospatial data, although there is also still use of annualized country-level statistics. Forecasting is enabling better predictions about the probability distributions of war, civil conflict, and one-sided violence (De Mesquita et al. 2020). Even so, such forecasts do not tell decision-makers exactly what to do, but rather what is likely to happen if they do nothing. Generating responsive action to the warnings remains the crucial outcome of the decades of technical development detailed in this article.

Navigating the warning-response gap – that is, the reluctance of political actors to respond when presented with compelling evidence – is

the final frontier of enhanced early warning. This review has traced the history and conduct of conflict early warning in international relations. It has shown how the theory and practice of early warning has advanced, not least due to rapid advances in both the quantity and quality of data and the rapid evolution of artificial intelligence. Indeed, a *fifth generation* of early warning is underway. This next generation may well overcome the warning-response gap by applying deep machine learning to generate increasingly parsimonious assessments that are, crucially, then matched to a range of possible real-time decision options, their inherent risks, and associated payoffs. This fifth generation is sophisticated and resource intensive, requiring collection and analysis of politically sensitive information in real time to train algorithms. For these and other reasons, the fifth generation may well remain in the domain of well-resourced defence and intelligence agencies and commercial companies for the foreseeable future. International organizations such as the UN or the OSCE, while tasked with conflict prevention, face political and financial constraints on adopting fifth-generation mechanisms for the time being.

Competing Interests

The authors have no competing interests to declare.

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