

On Benchmarking and Validation in Wargames

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Abstract: There are multiple arguments for and against wargames. Many scientists do not recognise the science in wargames. It is suggested that there is not enough literature relating to wargaming, for there to be any large-scale research into wargames. This is primarily because scientists often refuse to publish results, thus creating a vicious cycle where research is not published because there is not enough research being published. This ultimately deters researchers from studying wargaming in any serious fashion. Owing to this limitation, published work on the results, and protocols of wargames are scarce in scholarly research. Wargaming has considerably less academic focus with a fragmented and practical focus on design and benchmarking. This is surprising given the long history of wargaming (dating back to the early 1600's), when compared to the relatively recent history of other domains such as software engineering. To better understand the current state of research into wargaming in reference to benchmarking and validation, a scoping review (SR) was conducted. The scholarly research into wargaming reveals papers on general modelling, conflict modelling, influence modelling, evaluation of wargames, analytical tools, use of AI in wargame design, evaluation of predictive modelling in wargames, improving command and control through wargaming, and cost-benefit analysis for decision making. The initial analysis of the coverage of wargaming research, together with the limited number of papers found, indicate that there is a distinct lack of academic research into wargaming. Additionally, there is a wide variety of areas that are interested in the wargaming field, however, with no universal method of analysis or benchmarking, this limits the reproducibility of results, and the ability to judge the overall effectiveness of wargaming efforts. Wargame designers need to be able to assess wargame components to validate, compare, and predict the effects on gameplay and for decision-makers to draw conclusions with more confidence.

Keywords: Validation; Benchmarking; Reproducibility; Wargaming; Information Operations

1. Introduction

Wargames have long been in history. They were used to communicate ideas, understand trends, predict future outcomes, create strategies, test models and plans, and for training. The success or failure of a wargame lies in its ability to enable participants to express possible reactions and its connection to storytelling. The Military Operations Research Society (MORS) defines a wargame as a model or simulation involving two or more opposing forces using data, rules and procedures designed to depict an actual or fake narrative. Other organisations such as NATO define wargame as the use of a data processing system to represent selected behavioural characteristics of a physical or abstract system.

The earliest uses of first-generation (board game style) wargames are estimated at around 2300BC, while the use of second-generation (military simulation style) wargames is estimated at around the early 1600's (Caffrey 2019). Wargames can serve multiple purposes, including communication of ideas, understanding trends, predicting future outcomes, creating strategies, testing models and plans, and so on. The success or failure of a wargame lies in its ability to enable participants to express possible reactions and its connection to storytelling.

Compared to the long history of wargaming, research into other areas such as software engineering (which is comparatively a relatively recent phenomenon), has a vast amount of available published research. Therefore, it is surprising that there is not the same level of research into standardisation and efficiency of wargames as there is for software engineering.

1.1 Wargame Research

When considering investigating the efficacy of utilising research into wargaming for academic or serious professional use, it is worth considering the arguments for and against wargames, such as those mentioned in Wojtowicz (2019). It is suggested that many scientists do not recognise the science in wargames due to the lack of sufficient literature to support research on wargames. However, this can become a vicious cycle, if scientists refuse to publish wargaming results, due to wargaming results not being available.

The wargaming publication paradox often deters researchers from pursuing wargaming as a serious research discipline. This makes finding published scholarly work on results, protocols of wargames as well as dedicated researchers in the field hard to find for scholarly research.

2. Scoping Review on Benchmarking and Validation in Wargaming

We conducted a review on the scholarly literature available on benchmarking and validation in wargames.

2.1 Methodology

A Scoping Review (SR) was selected as it provides a reliable result in a reasonable amount of time when compared to a full Systematic Literature Review (SLR). This is supported by research by Munn et al. (2018), where it is suggested that a scoping review can suit a broader research focus and allow a better inclusion criterion for subject areas in which the exact nature of the subject is not well published in an academic sense, which is the case for wargaming.

In addition to taking considerably longer to perform, an SLR would be more appropriate for situations where there is a large number of published academic work, with which to be able to explain the current best practice (Fink 2019). The SR methodology published by Arksey & O'Malley (2005), with additional information and improvements to the methodology from Levac et al. (2010), was the chosen methodology for this research.

2.1.1 Research Question

This SR focuses on providing an overview of the current state of literature related to wargaming adjudication and benchmarking. Therefore, the following three Research Questions (RQ), were formulated to identify who benefits from further research into wargaming adjudication (RQ1), what is involved in adjudication and benchmarking (RQ2), and what sort of challenges are presented in the literature (RQ3). These are provided in Table 1.

Additionally, researchers will be able to use these findings to help better identify limitations and gaps in the literature, and potentially untapped future research in the wargaming domain.

Table 1: Research Questions

Number	Question	Motivation
RQ1	Who are the stakeholders that would benefit from a more standardised form of wargaming adjudication and overall benchmarking?	To identify the types of people/groups that will benefit from the increase in research into benchmarking and adjudication.
RQ2	What are the types of tools that are used in wargaming adjudication benchmarking	To help the researchers identify what sort of tools are used within the wargaming domain regarding adjudication and benchmarking.
RQ3	What are the reported challenges in employing adjudication benchmarking and/or standardisation that need to be addressed in further research?	To identify the current state of the wargaming domain; what is the current level of research? what challenges are mentioned (if any)? what are the gaps in research? and are there any future directions mentioned?

2.1.2 Search Strategy

The search process was conducted by two authors and was done independently using the SCOPUS abstract and citation database. For results that were unavailable in SCOPUS in full-text form, the GOOGLE Scholar web search engine and full-text database was used to source full-text versions of the documents for review.

The search string used to retrieve the documents was designed to utilise title, keyword, and abstract, to identify candidate papers that are related to Wargaming. The search process took place between February 2022 and April 2022. The review process was performed by the same authors individually. Abstracts were reviewed to identify relevant articles, and those that were not relevant to the subject were discarded. Additional information

was gathered from the SCOPUS search results, such as document type, document tags (key words), publication date, publication source, funding affiliation, and subject area.

2.1.3 SCOPUS Search String

The SCOPUS advanced search allowed the use of Boolean operators and regular expressions, in addition to limiting the search to specific areas of the document, such as title, abstract, and key words. The search was limited to papers published in 2012 or after to reduce the initial number of results.

The wargame search component was searched using the "TITLE-ABS-KEY" function, to limit the search to only the title, abstract, and keywords sections. This was decided as being necessary due to the frequent use of the term wargame in the body of many unrelated papers. Whereas the use of wargame in the title would suggest a focus on wargaming as the subject, and not in passing. The use of the wildcard operator '*' allows zero or more unspecified characters to appear after the section of quoted text. This allows us to target both the singular use of wargame, and the activity wargaming, in one search term.

"War gam" OR "Wargam*"*

The second component of both searches was the inclusion of capability, maturity, and adjudication into the search terms. This was enhanced with the use of the wild card operator in the same fashion as the previous search term, to broaden the use of all of the required words.

"Capabilit" OR "Maturity" OR "Adjudicat*"*

The final component was that of analysis and benchmarking into the search terms. Again, this was done in the same fashion as shown above.

"Assess" OR "Analy*" OR "Benchmark" OR "Bench mark" OR "compar*" OR "Study" OR "Investigat*"*

2.1.4 Study Selection

The two primary authors applied the SCOPUS advanced search strings mentioned in Section 2.1.3, to select the final set of papers used in the Scoping Review, the search results retrieved from SCOPUS are shown in Table 2. Further refinement of the selection was based on the criteria in Table 3.

Table 2: Full SCOPUS Search Results

ID	Authors	Title	Year
PID1	[No author name available]	Bridging multiple autonomous vehicle disciplines: Ensuring autonomous systems promote peace and stability on the world's oceans	2016
PID2	Athmer K., Gaughan C., McDonnell J.S., Leach R., Davis B., Truong K., Borum H., Leslie R., Ma L.	Enhancing army analysis capability for warfighter protection: TRADOC-RDECOM M&S decision support environment collaboration	2012
PID3	Banerjee P.	The wisdom of the road: Research and pedagogy on India-China and the Silk Roads Ethos (SRE)	2018
PID4	Barrett R., Deger-Sen S., Sen S.	Rational model of conflict: War and peace in South Asia	2013
PID5	Chen L., Kou Y., Li Z., Xu A., Wu C.	Empirical research on complex networks modeling of combat SoS based on data from real war-game, Part I: Statistical characteristics	2018
PID6	Christensen K.D., Dobias P.	Wargaming the use of intermediate force capabilities in the gray zone	2021
PID7	Colbert E., Sullivan D., Kott A.	Cyber wargaming on SCADA systems	2017
PID8	Colbert E.J.M., Kott A., Knachel L.P.	The game-theoretic model and experimental investigation of cyber wargaming	2020
PID9	D'Antonio C., Gower S., Young A., Teague E.	Non-kinetic operations for stabilizing government	2014
PID10	Davis P.K., Bracken P.	Artificial intelligence for wargaming and modeling	2022
PID11	De Lima Filho G.M., Kuroswiski A.R., Medeiros F.L.L., Voskuijl M., Monsuur H., Passaro A.	Optimization of Unmanned Air Vehicle Tactical Formation in War Games	2022
PID12	DeBerry W.T., Dill R., Hopkinson K., Hodson D.D., Grimaila M.	The wargame commodity course of action automated analysis method	2021
PID13	Dewoody R., Hayes J., Isnardi N., Kalinka J., Teague L.T.C.E.	Irregular warfare models for regional stability development	2014
PID14	Duong D., Bladon C.	Interfacing and validating models of the US army TRAC tactical war game	2012

ID	Authors	Title	Year
PID15	Duong D.V.	The design of computer simulation experiments of complex adaptive social systems for risk based analysis of intervention strategies	2012
PID16	Eichberg H.	Questioning play: What play can tell us about social life	2016
PID17	Fridheim H., Malerud S.	"Shall we play a game?" the pros and cons of wargaming reachback support in security risk analysis	2020
PID18	Fridheim H., Malerud S.	"Shall We Play a Game?" The Pros and Cons of Wargaming Reachback Support in Security Risk Analysis	2020
PID19	Gambone M.D.	Small wars: Low-intensity threats and the American response since Vietnam	2012
PID20	Goecks V.G., Waytowich N., Asher D.E., Jun Park S., Mittrick M., Richardson J., Vindiola M., Logie A., Dennison M., Trout T., Narayanan P., Kott A.	On games and simulators as a platform for development of artificial intelligence for command and control	2022
PID21	Grogan P.T., De Weck O.L.	Infrastructure System Simulation Interoperability Using the High-Level Architecture	2018
PID22	Guarda T., Vaca O.B., Pinguave M.P., Maldonado E.P., Augusto M.F., Orozco W., Pinto F.M.	Wargames applied to naval decision-making process	2017
PID23	Guo R.J., Sprague K.	Replication of human operators' situation assessment and decision making for simulated area reconnaissance in wargames	2016
PID24	Hart B., Hart D., Gayle R., Opper F., Xavier P., Whetzel J.	Dante agent architecture for force-on-force wargame simulation and training	2017
PID25	Hernandez A.	Advancements in scenario-Based learning through quantification of wargaming techniques	2017
PID26	Hernandez A.S.	Integrating simulation-driven decisions and business wargames to shape fiscal policies	2015
PID27	Hixson J.G., Miller B., May C.	Enhanced modeling and simulation of EO/IR sensor systems	2015
PID28	Hocaoğlu M.F.	Agent-based target evaluation and fire doctrine: an aspect-oriented programming view	2022
PID29	Hocaoğlu M.F.	Rule based target evaluation and fire doctrine	2019
PID30	Hodický J., Procházka D., Baxa F., Melichar J., Krejčík M., Křížek P., Stodola P., Drozd J.	Computer assisted wargame for military capability-based planning	2020
PID31	Jensen R., Teo G., Lunsford J., DeFalco J.A.	Designing a Distributed Team Training Experience to Balance Data Collection Needs With Natural Team Interaction	2021
PID32	Johnson B.	Predictive analytics in the naval maritime domain	2020
PID33	Kaivo-Oja J.	Three theoretical approaches to pirate entrepreneurship: Towards future studies of pirate entrepreneurship	2014
PID34	Kanniainen V.	Cyber Technology and the Arms Race	2019
PID35	Keller J., Colosi C., Nichols G.	Achieving high performance aircraft modeling in operational analysis software using a minimum complexity model	2018
PID36	Kim S.-J., Tsuruoka T., Hasegawa T., Aono M., Terabe K., Aono M.	Decision maker based on atomic switches	2016
PID37	Kodalle T., Sample C., Ormrod D., Scott K.	Thoughts about a general theory of influence in a dime/pmesii/ascop/irc2 model	2019
PID38	Largent M., Jensen G., Law R.	The Design for Maritime Singularity: Exploration of Human/AI Teaming and Organizational Carrying Capacity for the U.S. Navy	2018
PID39	Leonard W.B., Rinaudo C.H., Richards J.E., Goerger S.R.	An analytical model for system-of-systems sensor detection and defense efforts	2020
PID40	Mittal V., Davidson A.	Combining Wargaming with Modeling and Simulation to Project Future Military Technology Requirements	2021
PID41	Najgebauer A.	War games, simulation and CI tools for strategic planning	2020
PID42	Ormrod D., Scott K., Scheinman L., Kodalle T., Sample C., Turnbull B.	The persuasion game: Developing a serious game based model for information warfare and influence studies	2019
PID43	Rao D., Hu X., Wu L.	Performance analysis of parallel data distribution management in large-scale battlefield simulation	2014
PID44	Rossetti M.D., Bright J.	Bulk petroleum supply chain simulation modeling	2019
PID45	Rowe C., Seif Zadeh H., Garanovich I.L., Jiang L., Bilusich D., Nunes-Vaz R., Ween A.	Prioritizing investment in military cyber capability using risk analysis	2019
PID46	Ruvinsky A., Gonzalez M.E., Richards J., Salter C., Church J., McKee C.D., Seale M.	An Approach to Gamifying Acquisitions for Assessing Impact on Military Strategy of Nation States	2021

ID	Authors	Title	Year
PID47	Schwartz P.J., O'Neill D.V., Bentz M.E., Brown A., Doyle B.S., Liepa O.C., Lawrence R., Hull R.D.	AI-enabled wargaming in the military decision making process	2020
PID48	Schwarz J.O., Ram C., Rohrbeck R.	Combining scenario planning and business wargaming to better anticipate future competitive dynamics	2019
PID49	Sun P., Zhang J., Wang L.-H.	The Application Study on Accurately Search&Rescue of the Wounded on the land battlefield base on "beidou + Armored ambulance	2021
PID50	Vienhage P., Barcomb H., Marshall K., Black W.A., Coons A., Tran H.T., Nguyen T.M., Guillen A.T., Yoh J., Kizer J., Rogers B.A.	War-gaming application for future space systems acquisition: MATLAB implementation of war-gaming acquisition models and simulation results	2017
PID51	Wei X., Yang L., Cao G., Lu T., Wang B.	Recurrent MADDPG for object detection and assignment in combat tasks	2020
PID52	West J., Chu M., Crooks L., Bradley-Ho M.	Strategy war games: how business can outperform the competition	2018
PID53	Yu A., Yick K.L., Ng S.P., Yip J.	Case study on the effects of fit and material of sports gloves on hand performance	2019

Table 3: Inclusion (I) and Exclusion (E) criteria

Inclusion or Exclusion	Criteria
E1	Topic too narrow, or on a niche subject.
E2	Does not have a full-text available
I1	Must be related to Benchmarking and/or Adjudication in Wargaming

The SCOPUS search returned 53 documents published between 2012 and 2022. Of those 53, in the initial selection pass, 15 were discarded, with 13 discarded based on the I1 criteria, and 2 being discarded due to being a duplicate entry of an existing search result. These papers (PIDs 1, 2, 3, 15, 16, 17, 21, 27, 33, 36, 41, 47, 48, 50, 53) are shown in Table 2.

During the second pass, where there was greater attention placed on the content, and relation to the Scoping Review Topic. During this review process, 23 additional papers were discarded leaving 14 papers.

Of the 23 additional papers discarded, six were discarded based on E1 for being too narrow in focus (PID 5, 22, 25, 31, 37, 51), and 17 papers were discarded due to failing I1 (Topic too specific), after further investigation into the content of the paper.

The topics that these papers were primarily focused on were the following: Geo-Political Conflict (PID4), UAVs (PID11), Remotely Run Wargames (PID18), COA Predictive Analysis (PID32), Military Acquisitions (PID46), Ambulances (PID49), Target Evaluation (PID29), AI/Technology Singularity (PID38), Economics and Business Wargames (PID 26, 34, 44, 45, 48, 52), technology Roadmaps (PID40), Intrusion Detection (PID39), Data Distribution Analysis (PID43). These documents are listed in Table 2.

2.1.5 Data extraction

Data extraction was performed by one author, with a pre-defined data extraction form (**Error! Reference source not found.**) to record the extracted data gathered from the selected papers. The SCOPUS advanced search feature gave access to all the required data (such as document meta-data, search tags, and full-text files). Additionally, and Analyse Search Results options available in SCOPUS, such as Research Affiliation, Publication Location, and Study Sponsors.

Table 4: General Data Extraction Form

Item	Question	Related RQ
Stakeholders	What sponsors, research affiliates, government agencies, and militaries are related to the paper?	RQ1
Domain	What is the publishing domain that the paper is related to?	RQ1
Tags	What are the search tags of the paper?	RQ1
Tools	What are the wargaming tools/software that are mentioned?	RQ2
Challenges	What are the challenges mentioned (if any)?	RQ3
Future	What are the remaining research questions mentioned in the paper (if any)?	RQ3

3. Preliminary Scoping Review Result

3.1 Demographics

After filtering out unrelated documents, our remaining dataset contained 14 papers published between 2012 and 2022, with the largest number of yearly publications occurring in 2021 and 2022. We can see that there is a steady increase in publications related to Wargame Adjudication and Benchmarking (Figure 1). This increase in publications over time could suggest that there is an increasing interest in wargaming, especially from 2020 onward. However, due to the lack of data to go off (with the small number of overall publications), it is hard to say for certain that this is indeed an increase in interest.

Of the documents retained during the SR process, the document type was mostly Journal Articles (8), with slightly less Conference papers (5), and one Book Chapter.

3.2 Tools

The common tools (Table 5) that were discussed in many papers appeared to be primarily free tools (RStudio), or tools that are commonly available (such as Microsoft Excel, or Google Docs/Slides). Another common factor was the use of AI, modelling, and simulation tools, to evaluate decision making.

Table 5: Data Extraction Form for Wargaming Tools

Tool(s)	Related Papers
Hybrid Wargame Environment using Webex, Google Docs, and Google Slides. SCADA (Supervisory Control and Data Acquisition) systems. Game-theoretical Framework. Regression Modelling in RStudio. Machine Learning AI, and Agent Based Modelling. Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM).	(Christensen & Dobias 2021) (Colbert, E, Sullivan & Kott 2017) (Colbert, EJM, Kott & Knachel 2020) (D'Antonio et al. 2014) (Davis & Bracken 2022) (DeBerry et al. 2021)
Microsoft Excel, Crystal Ball, Vensim, Simulation Models (Lanchester Model, Monte Carlo Simulation).	(Dewoody et al. 2014)
Impact Computing's open-source model integration framework XBM, BayesOwl probabilistic inference engine. OpSim, Deep Learning Tools.	(Duong & Bladon 2012)
Dynamic Replicator of Decision Making (DRDM) Tool. Dante (built on the Umbra Simulation Framework).	(Goecks et al. 2022) (Guo & Sprague 2016) (Hart et al. 2017)
AdSiF (Agent-driven Simulation Framework).	(Hocaoğlu 2022)
Microsoft Excel. Custom Applications (simulated news feed, social media, common operating picture), Slack, NoSQL databases.	(Hodický et al. 2020) (Ormrod et al. 2019)

3.3 Future Work

Table 6 shows the extracted summary of the reviewed papers future work sections. It is worth mentioning that some papers did not include any reference to future work (PID20, and PID28).

Table 6: Extraction Form for Future Work

Future Work	Description	Related Papers
Additional Research	Research into different scenarios. Adjusting initial assumptions, to test different strategies.	(Christensen & Dobias 2021), (Colbert, EJM, Kott & Knachel 2020)
Additional Complexity	Adding in additional complexity to the model. Extend to whole planning process, allow more input from users.	(Colbert, E, Sullivan & Kott 2017), (Hodický et al. 2020)
Application of Model	Incorporating Model into a Wargame.	(D'Antonio et al. 2014)
Further use of AI	Further implementation of AI/Machine learning, particularly Cognitive Modelling. Replacing various processes with machine Learning. Implementation of automated online experimentation.	(Davis & Bracken 2022), (DeBerry et al. 2021), (Hart et al. 2017)
More Data	Research into operational data to replace Model data. Expanded collection of data, development of bots.	(Dewoody et al. 2014), (Ormrod et al. 2019)
Refining Processes	Fine tuning the processes to better measure performance and enhance consistency.	(Guo & Sprague 2016)

Table 7 shows that the primary publication source is the United States of America (9 publications), then Canada (2 publications), with the rest of the locations having one publication each. It is not surprising that the primary

publication location is the United States of America, given their large budget for military programs. The rest also coincide with large military budgets and needs.

Table 7: Scoping Review Document Source

Country / Territory	Documents
United States	9
Canada	2
Australia	1
Czech Republic	1
Germany	1
Turkey	1
United Kingdom	1
Undefined	1

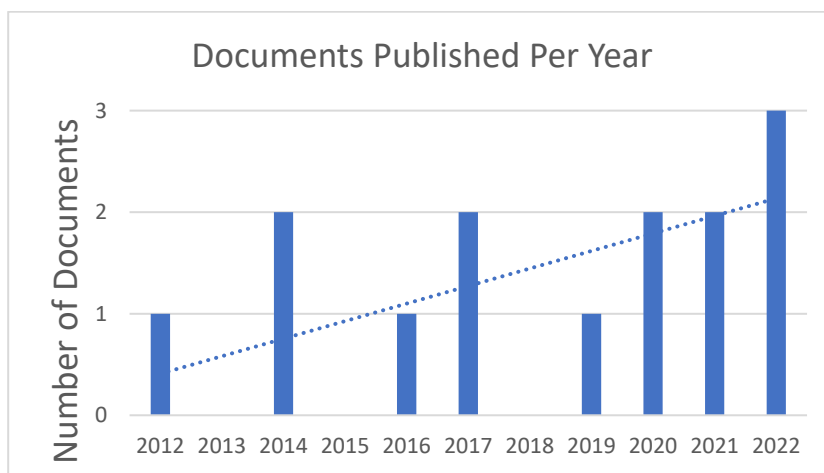


Figure 1: Scoping Review Documents Published Per Year

As we can see from Figure 1, There is a relatively low number of publications, until around 2020. Where the Journal of Defense Modelling and Simulation increased related publications from one per year, to three in 2022 (Figure 2). Suggesting that in addition to the overall increase in papers related to wargaming adjudication and benchmarking, the output per publisher increased over that period.

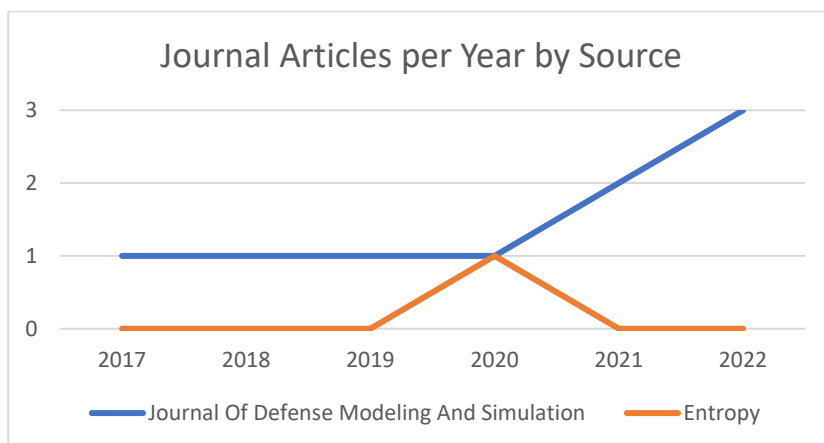


Figure 2: Scoping Review Journal Articles per Year by Source

As we can see from Table 8, the primary stakeholders who would benefit the most are world militaries (primarily the US, with 8 documents being associated with various US Army/Air Force departments). Private research laboratories, such as Defence Research and Development Canada, CAE, and RAND are the next largest group of stakeholders. Additionally, there were a selection of global universities, such as Yale, De Montfort, UNSW

Sydney, and Istanbul Medeniyet. Finally, military universities such as Command and Staff College of the German Armed Forces Univerzita obrany v Brne, and United States Military Academy at West Point.

Table 8: Scoping Review Document Research Affiliation

Affiliation	Description	Gov/Mil/Private	Documents
U.S. Army Research Laboratory	Foundational research laboratory.	Military (US)	5
Defence Research and Development Canada	Advisor, collaborative partner, and knowledge integrator for Canadian defence and security.	Private	2
NATO Headquarters Supreme Allied Commander Transformation	One of NATO's strategic commanders and commanding officer of Allied Command Transformation.	Military (NATO)	1
Agent Based Learning Systems	Global high technology company.	Private	1
CAE Defence & Security	Global high technology company.	Private	1
Communications-Electronics Research Development and Engineering Center	In-house science and engineering	Military (US)	1
Command and Staff College of the German Armed Forces	Military College.	Military (German)	1
Univerzita obrany v Brne	Military College.	Military (Czechia)	1
RAND Corporation		Private	1
Yale University	University	Private	1
Sandia National Laboratories, New Mexico	Global high technology company.	Private	1
De Montfort University	University	Private	1
Air Force Institute of Technology	Air Force academic education research, and continuing education.	Military (US)	1
United States Military Academy at West Point	US Army Officer education.	Military (US)	1
UNSW Sydney	University	Private	1
Istanbul Medeniyet University	University	Private	1

3.4 Domains

The remaining papers retrieved in the Scoping Review suggests that there is a wide variety of subject areas in which wargaming is being published. However, as can be seen in Table 9, most of the published work is found in the Engineering, Mathematic, and Computer Science domains, and the remaining research domains contribute a relatively small number of publications each.

Table 9: Scoping Review Research Disciplines

Subject area	Documents
Engineering	12
Mathematics	7
Computer Science	5
Arts and Humanities	1
Decision Sciences	1
Physics and Astronomy	1

3.5 Document Tags

The search keywords used for the publications of the SR showed a wide variety of different research areas, as shown in the word cloud in Figure 3. Of the 84 tags used in the documents. The ones that received the most uses were Modelling (7), Math (4), AI (3), and Simulation (3).

3.8 RQ3 What are the reported challenges in employing adjudication benchmarking and/or standardisation that need to be addressed in further research?

Of the documents that remained in the SR, the future directions involved such subjects as Additional Research (Christensen & Dobias 2021), Adding additional complexity to the computer system being researched (Colbert, E, Sullivan & Kott 2017; Hodický et al. 2020), application of non-kinetic operation models to test suitability (D'Antonio et al. 2014), the extended incorporation of AI and Machine Learning for better optimisation of processes (Davis & Bracken 2022; DeBerry et al. 2021; Hart et al. 2017), collecting data to better model real systems and incorporate a further collection of data in systems (Dewoody et al. 2014; Ormrod et al. 2019), and refining overall processes to improve performance (Guo & Sprague 2016).

What is in common between most of the future directions mentioned, was the necessity for the acquisition of more data, and more research into the area. Research into the systems and processes mentioned, together with the use of tools, will require a significant amount of data to either train or validate results.

4. Discussion and Future Work

From the analysis of coverage of wargaming research, and the small number of papers related to both wargaming, and adjudication/benchmarking (described in section 2.1.4), it can be shown that there is a distinct lack of total academic research into the area. There is a trend towards more research, especially from 2020 onwards, but it is still a relatively small number of publications.

The results show that the domains of publication are not restricted to one area, and there is a substantial institutional interest in developing wargames. However, even with the increased interest, and available research funding from a variety of governmental sources (primarily in the US), there still appears to be no universal method of analysis or benchmarking.

Further research will need to be performed into three areas, first what is the progress of publications into the field after the initial SR. Second, to expand the scope of research by identifying what types of wargames specifically are the most documented with regards to adjudication and benchmarking. Finally, continue assessment of the type of wargames that would benefit the most from a standardised form of adjudication and benchmarking, and what stakeholders prefer these types.

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References

- Arksey, H & O'Malley, L 2005, 'Scoping studies: towards a methodological framework', *International journal of social research methodology*, vol. 8, no. 1, pp. 19–32.
- Caffrey, MB 2019, *On wargaming: How wargames have shaped history and how they may shape the future*, vol. 43.
- Christensen, KD & Dobias, P 2021, 'Wargaming the use of intermediate force capabilities in the gray zone', *Journal of Defense Modeling and Simulation*.
- Colbert, E, Sullivan, D & Kott, A 2017, 'Cyber wargaming on SCADA systems', paper presented to Proceedings of the 12th International Conference on Cyber Warfare and Security, ICCWS 2017, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85018965308&partnerID=40&md5=2057ac3bb92b99a6db1c8d1de873d87c>>.
- Colbert, EJM, Kott, A & Knachel, LP 2020, 'The game-theoretic model and experimental investigation of cyber wargaming', *Journal of Defense Modeling and Simulation*, vol. 17, no. 1, pp. 21–38.
- D'Antonio, C, Gower, S, Young, A & Teague, E 2014, 'Non-kinetic operations for stabilizing government', paper presented to 2014 IEEE Systems and Information Engineering Design Symposium, SIEDS 2014, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-84903710483&doi=10.1109%2fSIEDS.2014.6829899&partnerID=40&md5=9f071bea57b5804809396d058f984c83>>.
- Davis, PK & Bracken, P 2022, 'Artificial intelligence for wargaming and modeling', *Journal of Defense Modeling and Simulation*.
- DeBerry, WT, Dill, R, Hopkinson, K, Hodson, DD & Grimaila, M 2021, 'The wargame commodity course of action automated analysis method', *Journal of Defense Modeling and Simulation*.
- Dewoody, R, Hayes, J, Isnardi, N, Kalinka, J & Teague, LTCE 2014, 'Irregular warfare models for regional stability development', paper presented to 2014 IEEE Systems and Information Engineering Design Symposium, SIEDS 2014,

- <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-84903718259&doi=10.1109%2fSIEDS.2014.6829898&partnerID=40&md5=2bb462b3f21bab6924e2ffe81c592160>>.
- Duong, D & Bladon, C 2012, *Interfacing and validating models of the US army TRAC tactical war game*.
- Fink, A 2019, *Conducting research literature reviews: From the internet to paper*.
- Goecks, VG, Waytowich, N, Asher, DE, Jun Park, S, Mittrick, M, Richardson, J, Vindiola, M, Logie, A, Dennison, M, Trout, T, Narayanan, P & Kott, A 2022, 'On games and simulators as a platform for development of artificial intelligence for command and control', *Journal of Defense Modeling and Simulation*.
- Guo, RJ & Sprague, K 2016, 'Replication of human operators' situation assessment and decision making for simulated area reconnaissance in wargames', *Journal of Defense Modeling and Simulation*, vol. 13, no. 2, pp. 213-25.
- Hart, B, Hart, D, Gayle, R, Oppel, F, Xavier, P & Whetzel, J 2017, 'Dante agent architecture for force-on-force wargame simulation and training', paper presented to Proceedings of the 13th AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment, AIIDE 2017, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85067103347&partnerID=40&md5=8b3b6657a74dd965a2bd85d8e96b3641>>.
- Hocaoğlu, MF 2022, 'Agent-based target evaluation and fire doctrine: an aspect-oriented programming view', *Journal of Defense Modeling and Simulation*, vol. 19, no. 1, pp. 107-21.
- Hodický, J, Procházka, D, Baxa, F, Melichar, J, Krejčík, M, Křížek, P, Stodola, P & Drozd, J 2020, 'Computer assisted wargame for military capability-based planning', *Entropy*, vol. 22, no. 8.
- Levac, D, Colquhoun, H & O'Brien, KK 2010, 'Scoping studies: advancing the methodology', *Implementation science*, vol. 5, no. 1, pp. 1--9.
- Ormrod, D, Scott, K, Scheinman, L, Kodalle, T, Sample, C & Turnbull, B 2019, 'The persuasion game: Developing a serious game based model for information warfare and influence studies', paper presented to European Conference on Information Warfare and Security, ECCWS, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85070013506&partnerID=40&md5=871656af04f1918e9452ab4f4c8aee6d>>.
- Wojtowicz, N 2019, 'From sandboxes to laboratories: evolution of wargaming into a method for experimental studies', *International Journal of Scientific and Research Publications*, vol. 9, no. 12, p. 399.