Integrated Analysis in a Synthetic Battle Space
Lessons from JPOW 2019

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ABSTRACT

This paper describes the collaborative R&D effort that has been conducted to develop and implement, for the first time in its history, an integrated analysis concept in the Joint Project Optic Windmill (JPOW) exercise series. Since the first edition in 1996, JPOW provides an extensive synthetic battle space - suitable for live-virtual-constructive participation - in which NATO and its coalition partners focus on enhancing interoperability in the Integrated Air & Missile Defence (IAMD) domain by exploring, testing and training future IAMD concepts and solutions.

The work presented is a joint effort of TNO Defence, Safety & Security, the Royal Netherlands Armed Forces, the German Air Force, and JPOW participants. This paper elaborates on the iterative and multi-disciplinary development and use of several state-of-the art data collection, monitoring, analysis, and visualisation tools enabling both in-situ/real-time data and performance analysis, as well as 'deep analysis' in a post-exercise analysis environment such as the Dutch IAMD Battle Lab. In addition, the organisational innovation that is required to successfully implement an integrated analysis concept will be highlighted. Based on lessons which were identified from JPOW19, this paper concludes by depicting the way ahead on how integrated analysis can enhance the effectiveness of synthetic battle spaces for both current and future military operations.

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Linda van der Ham has been working at TNO since 2012, after obtaining a MSc in Aerospace Engineering. As analyst in the field of Air & Missile Defence, she focusses on the evaluation of operational effectiveness of current and future systems, and operating concepts. In support of this work, Linda specialises in innovative methods of simulation and data analysis. She has been involved in the Joint Project Optic Windmill (JPOW) exercise series since 2013, for Concept Development & Experimentation (CD&E), scenario development, and in 2019 as lead of the concept development for integrated analysis and as core team member in the newly implemented Integrated Analysis Cell.

Lesley Jacobs joined TNO in 2001. As senior scientist, she is specialised in the fields of Military Operations Research, Training and Simulation. Her expertise is often called upon in military exercises, such as JPOW, and various Battle Labs. For JPOW19, Lesley was the lead for the R&D support provided by a multidisciplinary team of 25 TNO experts. In addition, she was a core team member of the Analysis & Assessment Control Group (AACG) and Joint Analysis Team (JAT) of JPOW19. Lesley obtained a MSc in applied educational science and technology, with a specialisation in simulation from Twente University in the Netherlands.

Hester Vermeiden has been working as analyst at TNO's Military Operations department since 2016, after having obtained her MSc in Aerospace Engineering. She is frequently involved in supporting the Royal Netherlands Armed Forces in experiments, exercises and tests, predominantly in the area of technical interoperability with Tactical Data Links. During JPOW19, she was a core team member of the newly introduced Integrated Analysis Cell supporting the Joint Analysis Team (JAT). Being certified in the NATO Lessons Learned methodology, JAT efforts were aligned accordingly.

Major Alexander Mac Lennan joined the Royal Netherlands Air Force in 1997. After graduation from the Royal Military Academy he started a career as Patriot weapon systems officer. Since 2015, Major Mac Lennan is chief of the CD&E Branch at the Knowledge Centre for Air & Missile Defence at the Netherlands Ground Based Air Defence Command (NLD GBADC). He is expert in Integrated Air & Missile Defence (IAMD), Theatre Missile Defence (TMD) and Missile Defence (MD), and a frequently invited guest lecturer. Since 2016, Major Mac Lennan has coordinated as JPOW project officer, the preparation and execution of the JPOW17 and JPOW19 editions. He is also the lead for the Dutch IAMD Battle Lab, and co-founder of the integrated analysis concepts described in this paper.

Lt.Col. Dirk Reinartz, joined the German Air Force in 1984. After graduating the Air Force Officer School in 1984/85, and Bundeswehr University Hamburg 1985-89, he became HAWK, ROLAND and PATRIOT weapon system officer/staff officer on unit and staff level, and CD&E consultant in the former Air Force Transformation Center. Since 2010, he is PATRIOT team leader in the SAM Weapons Assistance Team (System Integration and Checkout -SICO-Team), supporting the German PATRIOT armament organisation. For the JPOW19 edition, Lt.Col. Reinartz was chairman of the AACG & JAT. In addition, he took the organisational lead for introducing and testing the proof of concept for integrated analysis.

1.0 INTRODUCTION

The aim of the NMSG 2019 conference - *Towards the Next Generation Synthetic Battle Space* - is to identify how Modelling & Simulation (M&S) systems need to be modernised in order to represent the complex and contested future military operating environment and effects. This paper contributes to this aim by describing the collaborative R&D effort that has been conducted to develop and implement, for the first time in its history, an *Integrated Analysis Concept* in the Joint Project Optic Windmill (JPOW) exercise series [1].

Since its first edition in 1996, JPOW provides an extensive multinational synthetic battle space in which (NATO) coalition partners focus on enhancing interoperability in the Integrated Air & Missile Defence (IAMD) domain by exploring, testing, and training future concepts and solutions. An important feature of this synthetic battle space is that it is set up for enabling the participation of live/real platforms, systems and operational capabilities as well as virtual and constructive 'simulated' players. Therefore, an ongoing challenge is how to align interoperability and standardisation in architecture, set-up, and technical solutions between the M&S and the physical domain. The latter consisting of high-value, high-risk, and high-cost platforms, systems, and Command and Control (C2) capabilities with a considerable span of lifetime, and which comprise of both legacy systems and technologies as well as high-tech, state-of-the-art, and futuristic capabilities. This calls for both modernisation in the M&S domain, as well as finding appropriate solutions for being backward compatible with legacy systems and simulations in terms of interoperability standardisation. For JPOW, from a synthetic battle space design and development perspective, the three most important ones are - the ongoing need for developments in - the Distributed Interactive Simulation (DIS) protocol [2], the High Level Architecture (HLA) standard [3], and Tactical Data Links (TDLs), [4].

1.1 The need for next generation synthetic battle spaces

The need for synthetic battle spaces has been identified in various M&S communities for quite some time. For example, in 1995, a M&S vision statement of the United States Air Force highlighted the need for a Joint Synthetic Battlespace (JSB), i.e. '*an environment in which war fighters can train using real-world equipment, whilst being "virtually" immersed in a realistic contingency or wartime environment*'. In support of this vision, the need for military information processes to be more predictive, enabling commanders at the strategic, operational and tactical levels to anticipate rather than react was also identified. This is also referred to as Predictive Battlespace Awareness (PBA), [5]. The JSB strives to support training, acquisition, test and evaluation, and R&D [6]. To accomplish this, it operates at many levels of detail, including the engineering/technological level, entity level, mission level, operational level, and strategic level [7]. This is also seen in similar synthetic battle space initiatives, such as First WAVE [8], Collective Mission Simulation [9], Mission Training Through Distributed Simulation (MTDS) [10], and in The Netherlands: the IAMD Battle Lab [11], the Maritime Battle Lab [12], CABL [13], and the Simulation Battle Lab [14]. Such a broad scope makes it impractical and too costly to build all new simulation components. Synthetic battle spaces therefore often rely on existing components as much as possible. Hence, integrating legacy simulations and systems is seen as one of the most critical issues. By developing an Integration Framework (IF) this critical issue can be addressed. Such frameworks will reduce the effort required for large-scale simulation integration by an order of magnitude, and the construction of complex test beds, experiments, and exercises can be done with substantial less risk, time, and cost [7].

1.2 The need for next generation synthetic battle spaces in IAMD

Missile defence [15] plays a key role in minimising the threat of ballistic and cruise missiles to NATO and its deployed forces. Ballistic missiles present a problem from their destructive potential not only from a military aspect but also from a political aspect due to their potential as a terror weapon towards population centres and debarkation points. In parallel to the threat posed by ballistic missiles, there is an evolving threat posed by air breathing threats such as cruise missiles. Countering these threats is a combined and joint endeavour, and calls for extensive IAMD exercise opportunities, such as JPOW, amongst coalition partners [16].

Within the IAMD domain there are many additional forces driving the need for advancing synthetic battle spaces, in particular in the areas of operations analysis (OA) and technical analysis (TA). Examples are the ongoing proliferation of missile threat and technologies, the introduction of new platforms, sensors, and shooter capabilities, coalition Force Threat Evaluation and Weapon Assignment (FTEWA) capability developments [17] via initiatives such as the Maritime Theatre Missile Defence (MTMD) Forum [18], and the Allied Partners M&S initiative, which also aim at advancing the level of solutions for M&S, OA, TA, and data exchange amongst coalition partners.

1.3 The IAMD Battle Lab - a persistent next generation synthetic battle space

With the aforementioned activities in mind, both the potential of and the need for developing synthetic or virtual battle spaces through specific battle labs within the Royal Netherlands Armed Forces was recognised, and has led to the foundation of various battle labs. In general, there is a wide variety and diversity in battle labs. Battle labs can be set up to explore a specific topic for a limited period of time, e.g. for a specific capability development within a specific domain or can be setup as a multi-purpose exploration capability with an unlimited life span across domains and capability developments. Common denominators are that they offer a synthetic battle space tailored for exploration, experimentation, and testing, usually with flexible and scalable means - with varying subject matter experts, hardware, software, models, simulations, IT infrastructure, processes, guidelines, and knowledge - to be able to analyse and assess effects and/or a chain of effects in a certain battle space. These effects can be caused by change in the military domain, both internal and external, and can be of different nature, such as changes in doctrine & tactics, equipment, technology, organisation, threats or changes in the (operating) environment [12].

The mission of the IAMD Battle Lab (BL) of the Netherlands Ground Based Air Defence Command (NLD GBADC) is ‘to offer a unique operations analysis, experimentation, test and exercise capability by which risks for current and future IAMD operations are reduced and the effectiveness of operational deployments of the Royal Netherlands Armed Forces is enhanced’ [11]. The main tasks and responsibilities of the IAMD BL are to:

- Conduct operations and technical analysis, for e.g. defence design plans, TDLs, live firings, mission rehearsal (in preparation of actual deployments), and mission support;
- Support doctrine and tactics development;
- Perform concept development & experimentation (CD&E), [19];
- Conduct interoperability tests with coalition partners and national IAMD units/assets;
- Perform operational test & evaluation (OT&E) in support of weapon system upgrades and/or introduction of new platforms in the Dutch Ministry of Defence; and
- Support IAMD exercises, such as Constructive Optic Windmill and Joint Project Optic Windmill.

1.4 JPOW an ad-hoc next generation synthetic battle space

Over the past decades, JPOW has become a leading IAMD exercise, where an important focus is on experimenting with novel air and missile defence concepts, new tactics, techniques and procedures (TTPs), and testing future capabilities in a multinational live, virtual, and constructive (LVC) environment. In 2017, the Royal Netherlands Chief of Defence (CHOD) tasked the Royal Netherlands Army and the NLD GBADC to organise the fourteenth edition of JPOW together with the German Air Force via a binational core planning effort, supported by the participating nations - Denmark, Finland, France, Germany, Greece, Norway, Spain, USA, and the Netherlands - and agencies, such as the Competence Centre for Surface Based

Air & Missile Defence (CCSBAMD), the Missile Defense Agency (MDA) of the United States of America, the Warrior Preparation Center (WPC) of the United States Air Force, the NATO Communication and Information Agency (NCIA), and the Joint Air Power Centre of Competence (JAPCC).

JPOW19 was executed via CFBLNet [20] at five locations in The Netherlands, Denmark, Germany, and the United States of America, from the 1st until the 30th of March 2019, with over a thousand participants. The exercise combined weapon system simulations with a command post exercise, supported by distributed interactive simulation with both distributed and co-located participants. The simulation architecture combined the integration of live, virtual, and constructive simulation models. Standardised tactical communications combined secure voice and data links. Shared command and control networks made up the command control, and communications structure.

JPOW19 addressed the need for close cooperation among participating nations and organisations during IAMD operations with emphasis on mission planning, mission execution and interoperability. The exercise did not only address the current and near term ballistic missile threat, it also focused on unmanned aerial vehicles and conventional manned air threats. All functional areas of NATO IAMD were incorporated in the exercise design, i.e. Surveillance, Battle Management Command, Control, Communications, and Intelligence (BMC3I), Active Air & Missile Defence, and Passive Air & Missile Defence. Finally, JPOW19 provided an opportunity to assess IAMD TTPs.

1.5 Paper overview

The work presented in this paper is a joint effort of The Netherlands Organisation for applied Science & Technology (TNO), the Royal Netherlands Armed Forces, the German Air Force, and JPOW participants. The remainder of this paper will elaborate on the iterative and multidisciplinary development and use of several state-of-the art data collection, monitoring, analysis, and visualisation tools enabling both in-situ/real-time data and performance analysis, as well as deep analysis in a post-exercise analysis environment such as the IAMD BL at the NLD GBADC. In addition, the organisational innovation required to successfully implement an Integrated Analysis Concept will be discussed. Finally, the way ahead will be described, on how integrated analysis can enhance the effectiveness of synthetic battle spaces for both current and future military operations, based on lessons from JPOW19.

2.0 TOWARDS INTEGRATED ANALYSIS

Before detailing how integrated analysis for synthetic battle spaces in the IAMD domain can be defined, it is worthwhile to take notice of how analysis can be defined and how in several other domains integrated analysis has been defined.

NATO's Joint Analysis Handbook [21] gives the following definition of analysis, *i.e. 'the study of a whole by examining its parts and their interactions'*. The value of analysis is not to just develop findings, it is about developing findings with proof. As such, root-cause analysis is often referred to as key methodology. Analysis has to do with breaking down, dissecting, examining and/or reasoning. It is not about determining a value or rating. However, it can be initiated by an evaluation to determine what led to the eventual result. It is important to note that in this context, analysis is not the same as evaluation.

Within the United States National Oceanic and Atmospheric Administration integrated analysis refers to stock assessment methodologies that attempt to *'integrate multiple sources of data into a single estimation framework'*. Integrated assessment in this domain attempts to fit observations based on model predictions such as total landings by a fishing fleet, size samples of landings, standardised catch per unit effort by fleet, fishery-independent surveys, and tagging records on movement, growth, and recoveries [22].

Within the trading community, integrated analysis is seen as a means to regain an edge for trading, *'an integrated approach means fusing all the beneficial elements of fundamental studies, technical analysis and consensus figures into one immensely powerful blend of comprehensive and thorough analysis'*.

Due to recent innovations in technology, allowing the rapid assessment of large volumes of data, integrated analysis has become a viable tool for retail traders. Qualifying stocks that meet specific and tested criteria from precomputed lists can be collated and cross-referenced to produce advanced shortlists for further analysis. However, how is such an integrated analysis approach actually beneficial to a trader? Conceptually, a trader is faced with an intellectual challenge every time (s)he prepares to open or close a position. That challenge can be viewed as a problem which requires some form of solution. With integrated analysis, the philosophy for solution is to consider as many perspectives (or angles) as possible, before committing money to the market. The trader is aiming to only choose trades which meet multiple criteria [23].

According to the Psychological Methods Journal, integrative data analysis refers to *'the simultaneous analysis of multiple data sets'*. The main focus is on handling multiple types of data and having the ability to synthesise data into useful and timely information types [24]. The focus on synthesis and meta-analysis is particularly worthwhile to note for the IAMD domain. According to the field of Socially Responsible Investments (SRI) integrated analysis is a strategy in which analysis of environmental, social and economic issues contributes to better financial analysis by identifying additional sources of risk and opportunity, thereby contributing to better overall investment decision-making [25].

The four examples above highlight four different approaches on how to benefit from integrated analysis. Although differences in application can be noted, fundamental similarities can also be observed. For synthetic battle spaces, the main requirements for an integrated analysis concept are: the ability to handle large amounts of different types of data, the ability to monitor and analyse (near) real-time as well as having the ability to perform post-event (off-line) analysis, the ability to compare observations against (M&S) predictions, the ability to assess solutions against multiple criteria, the ability to synthesise and/or perform a meta-analysis, the ability to support decision making, and last but not least the ability to support (organisational) learning.

2.1 The need for integrated analysis at JPOW

At the After Action Review (AAR) Conference of JPOW17, which preceded the Concept Development Conference for the JPOW19 edition, the need for a more profound and timely (near) real-time analysis process and means during execution as well as the need for more profound post-exercise analysis options were identified by various stakeholders [26]. This has led to the definition, design, implementation, and first operational test & evaluation of an Integrated Analysis Concept during JPOW19, which also supported a so-called deep analysis effort in the post-exercise phase, with novel analysis tools, methods and techniques. Deep analysis is described in more detail in Section 3.3. After JPOW, these solutions have been transferred to the IAMD BL of the NLD GBADC in support of future JPOW editions and other BL events.

2.2 The role of a Joint Analysis Team at JPOW

The organisation and execution of the JPOW exercise series has mainly been set up in accordance with the BISC75-3 guidelines for NATO exercises [27]. Eight control groups were responsible for the preparation, execution, evaluation of JPOW19, and eventual transfer of main lessons to the JPOW21 edition. These are: the Exercise Control Group (ECG), the Concept Development & Experimentation Control Group (CDECG), the Scenario, Intel & Simulation Control Group (SISCG), the Operations Control Group (OCG), the Interoperability Control Group (ICG), the Information Management Control Group (IMCG), and the Analysis and Assessment Control Group (AACG).

Although monitoring and analysis is done at multiple nodes in the Exercise Control (EXCON) organisation as well by participating units/entities themselves, the AACG took the lead in coordinating and integrating analysis efforts for JPOW19, with a special focus on advancing the monitoring and analysis toolset for the EXCON organisation. During the execution phase the AACG transformed into a Joint Analysis Team (JAT). Next to the twelve AACG core team members, seventy-five JAT members from participating units joined the JPOW19 JAT effort.

The mission of the JPOW's Joint Analysis Team (JAT) is to 'help participants improve their performance on all aspects of IAMD by facilitating data collection, analysis and assessment of this obtained data'. Baseline for the work of the JAT are the participant's objectives. Extraction of metrics from these objectives was done, whenever possible. However, when metrics could not be extracted a general assessment of mission performance was made [28].

Objectives are key to the scenario design, (dynamic) scenario management during execution, as well as the analysis and assessment effort. By providing objectives, participating units/entities specify the requirements which the scenarios have to meet. In other words, objectives shape both CD&E and mission execution phase, as well as the analysis and assessment effort, leading up to a Lessons Identified Action List (LIAL) for both exercise organisation and participants. Objectives are intended end-results, to be accomplished by a JPOW unit/entity. They should be expressed in terms of desired behaviour or skill level, conditions under which it has to occur, and benchmarks against which it will be assessed [29].

Figure 1 presents the generic joint analysis and assessment loop for JPOW. Please note the difference between a Lesson Identified (LI) and a Lesson Learned (LL). Although the latter is always the aim, the accomplishment of LLs is a shared responsibility of all those involved [29]. For JPOW the actual achievement of a LL often is to be realised in the post-exercise phase or next JPOW edition [28].

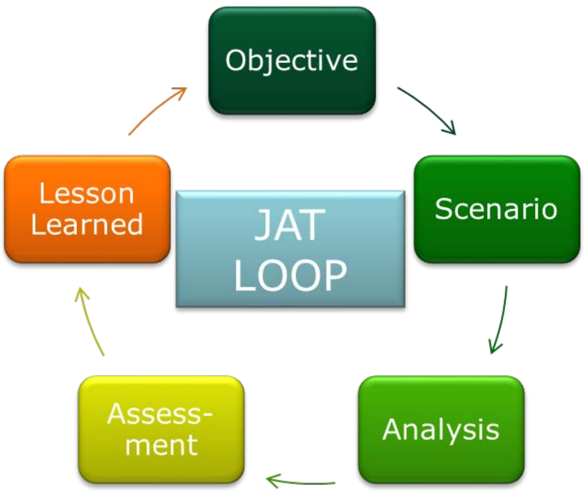

Figure 1: Joint Analysis & Assessment Loop [28]

In support of its joint analysis and assessment tasking, the AACG is responsible for developing a Data Collection and Assessment Plan (DCAP) [28]. Besides describing the data collection, analysis and assessment effort, this plan also describes the roles and responsibilities for the JAT organisation. The DCAP identifies the exercise and unit objectives to be assessed and the types of data to be collected ,such as, deficits and shortcomings of organisational matters, doctrine, procedures, interoperability and other relevant fields of interest. The DCAP also provided participants with a template for structuring their objectives. The objectives template included fields such as: an overall objective description, measures of effectiveness

(MOEs), measures of performance (MOPs), scenario and/or exercise conditions, and data collection requirements. MOEs focus on achieving the overall mission and execution of assigned tasks. MOPs are measurable/observable breakdowns of a specific MOE, are more detailed, and provide a quantitative and/or qualitative baseline to be met by a force/unit [28].

The JPOW JAT effort clearly supports an objectives-based data collection, monitoring and analysis effort. However, it requires substantial effort and skill by all those involved. In addition, from a daily exercise point of view, time is always lacking for in-depth and yet timely monitoring and analysis process, in support of the daily learning processes. This outlines, in addition to the AAR results as described in section 2.2, the need for advancing the joint analysis and assessment efforts in JPOW.

3.0 Integrated analysis approach for JPOW

Part of the AACG/JAT role in the JPOW EXCON organisation was previously known as adjudication[1] and was limited to the assessment of engagement results. It was expanded for JPOW19 into an Integrated Analysis Concept to develop a more thorough understanding of the actions of the participating units, and to not only focus on the result of these actions. The main objective was to increase the training value of the exercise on a tactical and operational level by increasing the level of organisational learning for the JPOW EXCON organisation, its control groups, and participating IAMD units/entities.

In addition to the objectives-based analysis approach as summarised in the previous section, for the first time in JPOW, a data driven analysis effort was implemented and tested by using new methods, tools, and technologies. This also led to the set-up of an Integrated Analysis Cell in the JPOW19 EXCON organisation, which could now focus not only on the analysis of 'what' happened but also dive into the analysis of 'why' something happened during a specific scenario event. The data driven approach relies on synthesis of logged data and a comprehensive view on the data, such that in addition to the analysis of issues related to individual participants' objectives also lessons can be identified on a joint level, e.g. within a certain operational area of interest such as active defence, passive defence or joint defence against air breathing threats and ballistic missiles. All logged data was stored in a central database, in which analysts could submit different (near real-time) queries to integrate data and investigate certain events more quickly, more detailed and in a more comprehensive manner.

3.1 Alignment with NATO LL processes

In support of the integrated analysis design for JPOW19, NATO's Lessons Learned (LL) Staff Officers Course was attended by three JAT core team members. This was done to align the JPOW JAT loop and LL processes of the JPOW organisation, its control groups, and participating units/entities with NATO's LL processes, methods and techniques [29]. The LL processes are in fact a continuous application of the OODA loop:

- Observe → determine the analysis requirement;
- Orient → describe causes of observed effects, impact, and relationships (analysis);
- Decide → determine Course of Actions (COAs), appropriate action(s) is/are chosen, and an action body is appointed for each Lesson Identified (LI) in the Lessons Identified Action List (LIAL);
- Act → appointed action body executes the action(s) to ensure that a LI transfers into a LL.

[1] Adjudication is originally a legal term, and refers to making a formal decision (judgement) after having reviewed arguments and evidence. This way it is also used in wargaming, where it refers to the procedure to impartially resolve the outcome of interactions between sides in a game [30]. In previous JPOW exercises, the task of the adjudication cell was mainly to decide when a unit was taken out by a threat and should be given a 'time-out' in the exercise.

The three key elements of a LL Capability are: structure, process, and tools. This means that having skilled and adequate LL personnel (for JPOW these are mainly the JAT members), a common LL process (i.e. the JPOW DCAP), and tools to support collection, storage, staffing and sharing of LL information, are essential. The desire to learn from others as well as to share own learnings has to be supported by effective leadership with timely and effective decision making, putting emphasis on the value of a LL capability, and creating an open learning environment. Critical success factors for any LL Capability are: leadership, mindset, information sharing, and stakeholder investment [29]. In JPOW these responsibilities are bestowed mainly upon the leadership of the AACG.

3.2 Objectives-based and data driven analysis

An integrated analysis concept has to take into account all aspects which play a role in the course of an exercise, experiment and test, such as the objectives, scenarios, vignettes, simulation, connectivity, tactical data links, tactics and procedures. This also calls for the integration of data, knowledge and analysis efforts from different control groups, participating units and JAT observers. For JPOW19, this was done according to the framework as shown in Figure 2.

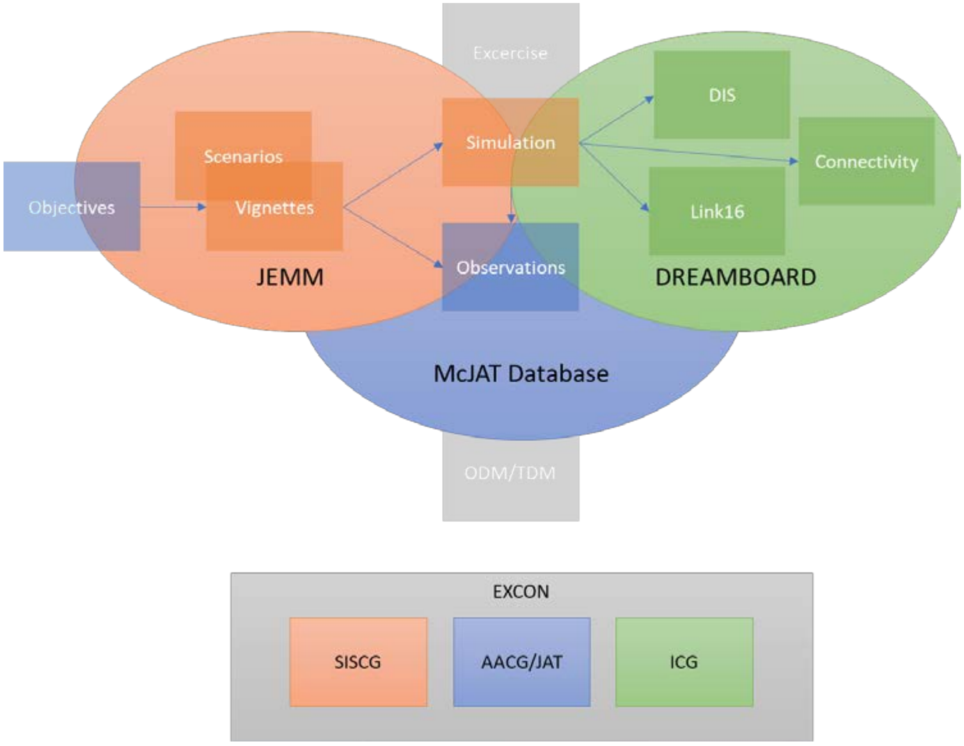

Figure 2: Objectives-based & data driven analysis approach

Monitoring and analysis was performed at various nodes in the EXCON organisation. Via the introduction of new tools, such as JEMM and McJAT, an objectives-based data analysis approach (typically focussing on the analysis of qualitative data provided by the objectives, scenarios, vignettes, and JAT observations) could be combined with a data driven data collection, monitoring, and analysis approach provided by a DREAMBOARD database, an analysis application and various dashboards, in addition to other analysis tools already available in the EXCON organisation. The latter approach typically focusses on the analysis of quantitative data available via the DIS and TDL network, as well as the connectivity status of all participants. More information on these tools is provided in section 4.2.

Figure 3 gives a functional overview of the integrated analysis effort for JPOW19, starting with pre-JPOW activities such as defining the DCAP (process), giving training to all JAT members via JAT academics (structure), and the development of an integrated analysis concept based on toolset of already existing and new tools (see section 4.2). The figure zooms in mainly at the daily integrated analysis effort during the execution phase, also referred to as the in-situ or near-real time monitoring and analysis process. The main objective for this phase was to support and enhance the quality of the Operational Debrief Meeting (ODM) and the Tactical Debrief Meeting (TDM) by improving the quality, speed and integration of all available data via new tools and methods into an integrated analysis effort. Please note that in JPOW19, due to the high number of participants, two parallel daily debrief sessions were conducted in support of the operational and tactical IAMD levels.

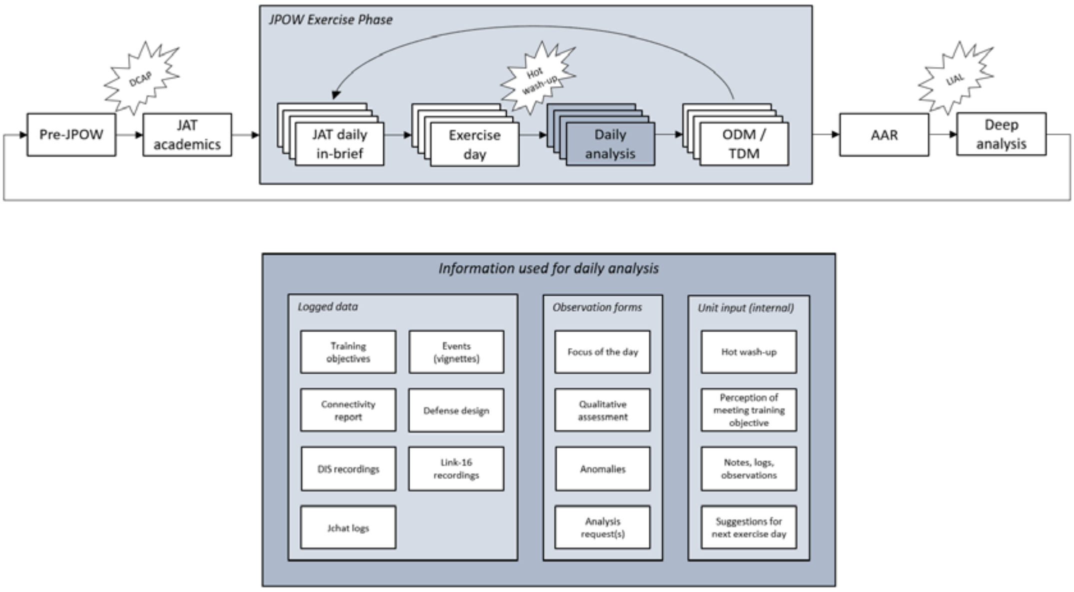

Figure 3: Integrated Analysis for JPOW19

The JPOW execution phase ended with a plenary After Action Review (AAR) with approximately five hundred participants. Main lessons were captured in Intermediate Data Collection Sheets (IDCS), AAR reports, First Impression Reports (FIRs), LIALs, and the Final Exercise Report (FER). After JPOW19, a deep analysis effort was performed, which led to additional lessons identified for the JPOW21 edition.

3.3 Deep analysis

Deep Analysis is a term commonly used in the IAMD community for detailed analysis of a live firing event of, for example, a single missile in a certain C2 and sensor environment, based on a specific threat, and scenario. For JPOW, deep analysis has been defined as the part of the integrated analysis concept that provides a solid basis for a more thorough post-exercise analysis effort, both in terms of integrating operations analysis and technical analysis, and with a special focus on off-line and faster than real time analysis means.

In the aftermath of JPOW19, members of the AACG and ICG were able to perform operations and technical analyses at various nodes in Germany, The Netherlands, and the USA. To follow-up on this distributed analysis effort, a Technical Interchange Meeting (TIM) was organised by the ICG. The main topic for analysis of this TIM was the degradation of the Common Operational Picture (COP) with issues such as misidentification and dual tracking of simulated objects which could detract from the situational awareness of the participants. Therefore, the joint analysis effort in this week-long TIM focussed on detecting interoperability issues based on a technical analysis of TDL and DIS data performance. In particular, the adherence to standards and reporting of tracks was carefully analysed. The post-exercise analysis report of the ICG serves as a first investigative assessment, while special reports with a LIAL for individual units are made to support their necessary preparations for the JPOW21 edition, and to improve the training value of the next JPOW edition from an interoperability perspective [31].

Examples of operations analysis in a post-execution phase that can be supported with the integrated analysis approach are the ability to assess the effectiveness of the planning of the overall IAMD mission, the execution of layered defence designs, and the investigation of joint operating issues, upon request by participants and the JPOW EXCON organisation. Participating units/entities can also perform their own specific deep analysis effort by analysing their performance based on, for example, root cause analysis of relevant exercise data which are available upon request.

4.0 INTEGRATED ANALYSIS METHOD AND TOOLING

In the preparation leading up to JPOW, participants provided objectives, such that the CD&E and exercise scenarios could be written to accommodate these. Most of the simulated events during the exercise, also referred to as vignettes, were therefore directly related to a (training) objective and were used to focus the analysis efforts. The Main Event List (MEL) contains these vignettes delineated in location and time, with an indication of the objectives from which they originated. To support the daily debriefs, a number of relevant vignettes were selected to be analysed thoroughly. This relation between objectives and scenario also helps to focus the attention of the JAT observers and their respective units.

The scenarios were recorded, allowing for replay faster than real-time without affecting the simulation environment. This was used during the daily in-brief for the JAT observers to give a global impression of the daily scenario as well as an indication of when specific events were scheduled to occur. It was also used to visually support the daily debriefs with replays of relevant occurrences. Apart from the pre-selected vignettes, other interesting situations might occur which would require attention in the daily debriefs. Upon request, re-runs of specific parts of the scenario could be done afterwards by filtering all simulation data in location and time.

4.1 Improving daily data collection

The data driven analysis approach relies on a variety of logged exercise data. For JPOW19 this consisted of: observation forms, DIS, Link-16, scenario descriptions (including MEL and shotplans), leaker charts, defence designs, communications logs, and questionnaires.

Daily *observation forms* provided a framework for qualitative assessments by the JAT observers. The forms were developed by the AACG and are based on the NATO LL format, describing: Observation, Discussion, Conclusion, and Recommendation (ODCR), [29]. All observations are related to a specific (training) objective, and provide the possibility to submit a request for a specific investigation/analysis by the Integrated Analysis Cell.

The *DIS 6.0* protocol was used to s(t)imulate all objects in the JPOW19 scenarios, and provided relevant data on the simulated performance of all LVC participants. For the next JPOW edition, an upgrade to the DIS 7.0 protocol is needed, especially in support of interrogation of Identification of Friend or Foe (IFF) at Mode 5.

Link-16 was used as predominant TDL during JPOW19. Link-16 enables the communication of tactical data between units/entities, mainly for common situational awareness, engagement coordination, and status reporting. In LVC exercises such as JPOW, constant monitoring and analysis in the EXCON organisation is required of both DIS and TDL network to be able to verify the ground truth (scenario delivered via DIS) with the perceived truth (via TDL). This subsequently enabled the Integrated Analysis Cell to answer specific participant questions with respect to their (joint) performance in a certain area. In the Integrated Analysis Cell, Link-16 analysis was focused more on operational aspects than on technical performance (connectivity) and participants' adherence to NATO standards and other data exchange agreements. This was monitored and analysed in the ICG.

The *scenario descriptions* contained vignettes, the MEL, shotplans, and threat definitions for DIS. They were captured in the script for the scenario stimulation tool PELORUS (see section 4.2). For JPOW19, the general storylines and MEL were made available in text via the scenario management tool JEMM (see section 4.2).

A so-called *leaker chart* helps to identify an (un)successful defence against ballistic missiles and to identify root causes, e.g. why a particular engagement was successful or not. As such, it provides a common Terms of Reference (TOR) for the analysts. For ballistic missiles such a reference chart was already available at previous JPOWs. At JPOW19, for the first time, is was also possible to assess the effectiveness of defence against air breathing threats (ABT), a far more complicated analysis requirement, based on a leaker chart. Also during JPOW19, possibilities for the automation of these leaker charts was looked into, which resulted in various dashboard views with desired statistics, and which might also become available as real-time status display in future exercise editions.

The *Defence Design* is the overall result of the IAMD mission planning process, which consist of multi-layered defence plans. It contains the defended areas and allocated positions of IAMD units in the scenario. It provides, next to the leaker charts, an important baseline or TOR for investigation and analysis

Communication logs consisted of chat, voice (sometimes), notes based on phone calls, written questions and responses. By correlating these type of data to anomalies detected in the DIS/L16 logs it was possible to pursue more in-depth investigation and analysis. This is due to the fact that decision making in complex warfare situations can evoke multiple courses of action that have to be investigated carefully via appropriate qualitative data analysis means, mainly focussing on why a certain decision was made by operators/units/C2 entities, and supported by more quantitative analysis means focussing on the outcome of such decision making and/or actual adherence to interoperability standards.

In addition to the daily data collection via observation forms, two *questionnaires* were sent out to the participants and control groups in support of the post-exercise analysis effort. These were an *Intermediate Data Collection Sheet (IDCS)*, which was released at the end of the CD&E phase, and an *AAR* r*eport* t*emplate*, which was released at the end of the execution phase. The former contained the qualitative assessments on the final test & integration phase and the CD&E phase, including academics, Combat Enhancement Training and Force Integration Training (CET/FIT). The latter document focussed on collecting data on the mission execution phase and the planning conferences prior to the exercise. The analysis of the IDCS resulted in a LIAL, and the main lessons of the AARs were captured in the First Impression Report (FIR) of the AACG [32], and the JPOW19 Final Exercise Report (FER), [33].

4.2 Expanding the toolset

In support of the JPOW EXCON organisation, various M&S and analysis tools are brought together in support of scenario development, scenario management, enhancement of the scenario with constructive simulations, monitoring, visualisation, logging, replay and analysis of DIS and TDL performance. Similar to other ad-hoc synthetic battle spaces, JPOW's toolset is defined by a joint, international, scientific, industrial, and NATO toolset. For each JPOW edition, investigations are made to see if the EXCON toolset (still) suffices or that areas of improvement are deemed necessary. Until the JPOW17 edition, the integrated use of these EXCON support tools for analysis was not foreseen.

In synthetic battle spaces with large amounts of data-exchange, it proves beneficial to have similar types of tools available. It ensures robustness and flexibility, and moreover it provides the ability to cross-reference results of a specific monitoring, investigation, and analysis process. This contributes substantially to the trustworthiness and validity of a joint analysis and assessment effort. The main tools for providing EXCON support in the JPOW exercise series are: PELORUS, JROADS, GRACE, JODA, GAMEBOARD, TDACS, and ADIVS. A brief summary of each tool (suite) is given below.

PELORUS is an extensive s(t)imulation suite developed by JESSIX for the US MDA [34]. It was procured by the Royal Netherlands Armed Forces in support of the delivery of synthetic battle spaces for the IAMD domain. With PELORUS it is possible to develop, test and run extensive LVC scenarios, and enhance these scenarios with both scripted and dynamic play of constructive entities, such as additional blue forces and red forces. In support of the JPOW execution phase additional manning support and a substantial set of extra PELORUS systems was provided by JESSIX to the EXCON organisation.

The *Joint Research on Air Defence Systems (JROADS)* tool suite [35], developed by TNO, offers an advanced, modular and flexible simulation environment in a wide range of military domains. JROADS models can be used at various levels of detail, such as running high-fidelity effectiveness analyses, supporting (inter) national exercises and experiments (CD&E), delivering testbed support, and running war games. For JPOW19, JROADS was used for various purposes. During the risk reduction tests prior to the exercise execution phase, it was used as test and analysis environment. During the actual exercise execution, JROADS was used to enable the:

- monitoring and analysis support in the EXCON organisation by TNO analysts in the ICG area;
- participation of two Air Defence and Command Frigates (ADCF) of the Royal Netherlands Navy via a mobile maritime battle lab set-up, which consisted of an integrated ADCF Combat Management System - JROADS - Linpro TDL solution; and
- participation of the Royal Netherlands Army with a JROADS Army Ground Based Air Defence System (AGBADS).

The *Generic Reconstruction And Computing Environment (GRACE)* is a tool suite developed by TNO and the Royal Netherlands Navy for reconstruction and analysis [36]. In GRACE, data from multiple sources, such as log files and live feeds, can be combined and synchronised in time, allowing analysis and (re)-play, for example, in 2D/3D visualisations, charts, graphs, timelines, and tables. During live exercises and/or live firings GRACE is used both for analysis on-board of naval vessels and for post-exercise/post-mission analysis at the Maritime Battle Lab of the Royal Netherlands Navy [12]. For JPOW19, GRACE was mainly used in the ICG area of the EXCON organisation as technical analysis tool.

JODA (Joint Operations Data Analysis) is the logging & replay application for GRACE. It can simultaneously record multiple network traffic streams, store it, or redistribute the data over a data bus. It can simultaneously replay live streams or recordings on the network again, with or without a delay. Timestamps in the replayed data can be updated, so the resulting data stream is effectively a live data stream. It is capable of handling various types of data, such as TDLs and DIS. In combination with analysis tooling, such as GRACE and DREAMBOARD, the recorded data can be inspected and visualised live, enabling the analysts to monitor and analyse an event directly.

GAMEBOARD provides a 2D visualisation of the synthetic battle space and was developed by TNO for, amongst others, NCIA’s Integrated Test Bed [37]. Gameboard provides a complete overview of the simulation entities on the network, either as truth data provided by the threat generation tools, as perceived data in an operational context, or as a combination of both superimposed on a single viewer.

The *Tactical Data Analysis and Connectivity System (TDACS)* is developed by Märzen (USA) as a datalink management tool. It provides means for logging, visualising and analysis of Link-16 messages. For JPOW the BMD adjudication plugin was made available, which allowed for analysis of individual ballistic missile shotlines with all related detections, tracks and engagements [38]. The main use of TDACS in the JPOW EXCON organisation is aimed at technical monitoring and analysis of TDL performance, connectivity issues, and assessment of BMD engagements.

The *Air Defense Interoperability Validation System (ADIVS) II* is developed by Peraton (USA) for analysis and monitoring of TDLs. It is used by the German Armed Forces for real-time situational awareness during interoperability testing and training in air defence operations exercises [39]. AT JPOW, ADIVS was used mainly for technical monitoring and analysis purpose in the ICG area of the EXCON organisation.

In the aftermath of the JPOW17 edition, the need for integrated analysis, mainly focussing on the integration of technical and operations analysis on various levels and locations in the exercise, as well as the integration of analysis means for both Air Defence and Missile Defence (i.e. IAMD analysis) was identified. This led to the introduction of JEMM, McJAT, and DREAMBOARD. Via this approach, the JPOW organisation was able to leverage as much as possible on the proven value of existing tools and their unique capabilities, and at the same time enhance joint monitoring and analysis capabilities for the JPOW19 edition via an iterative development and test approach under guidance of the AACG/JAT. Based on the availability of the aforementioned tools, McJAT, JEMM, and DREAMBOARD were subsequently prepared, fielded and tested during JPOW19.

The *McJAT* database was developed by the German Air Force for data collection and data storage of qualitative assessments made by JAT observers and participants. McJAT is based on a MS Access database and the ODCR format of the observation forms as displayed in figure 4. These forms could be accessed via a dedicated JPOW19 SharePoint environment and were stored in the database. Prior to the JPOW execution phase, JAT members received training in how to support integrated data collection and analysis and how to work with all tools available. During JPOW19, various improvements on accessibility and usability of the McJAT database were made on the spot by the AACG, based upon direct feedback from JAT members and the IMCG.

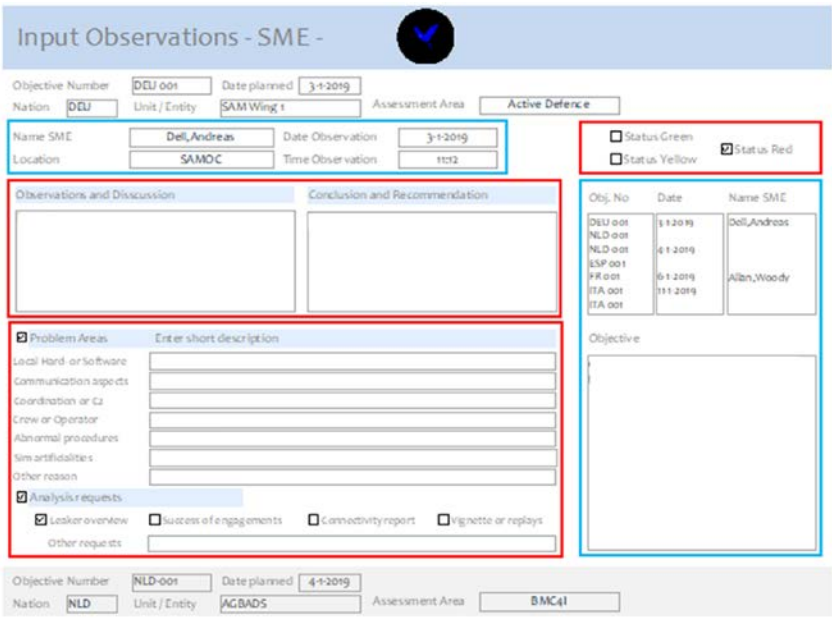

Figure 4: Overview of the McJAT database & ODCR format for entering observations

The *Joint Exercise Management Module (JEMM)*, displayed in figure 5, is a NATO tool developed by NCIA for the Joint Warfare Centre (JWC). It is currently in use by most of the NATO members to support their (inter)national exercises, such as VIKING and MSG-106 NETN. JEMM provides an integrated Exercise Management Environment to improve awareness in and provide control mechanisms to an EXCON organisation. It can be used as planning and management tool for scenario development and scripting, and contains scenario events and injects, based on storylines and participant objectives. For JPOW19, JEMM was used to a limited extent by the SISCG for scenario development. During the exercise the use of JEMM was tested by the EXCON organisation and several participants for monitoring the overall execution and the play of non-simulated events, such as the intel scripts.

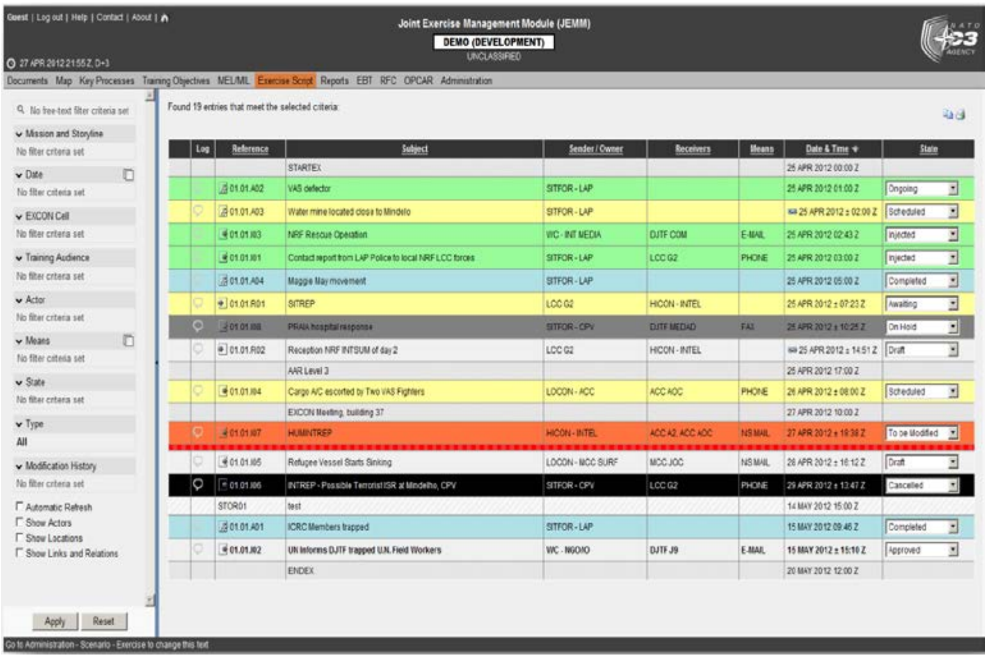

Figure 5: Joint Exercise Management Module

The *Dashboard for Real-time Event Analysis & Monitoring (DREAMBOARD)* has been developed by TNO, in a multidisciplinary and iterative R&D effort, for synthetic battle spaces such as JPOW and the IAMD BL. The aim of this R&D effort was to provide new solutions for integrating the means for technical and operations analysis. During JPOW19, the goal was to both demonstrate and explore these solutions, in addition to (and making use of) the already existing means and tools such as GRACE and JODA. This was done by using advanced M&S, technical & operations analysis, and data-science methods and techniques.

DREAMBOARD's front-end consists of two types of widget-based client applications: a dashboard view and an analysis application. The dashboard view enhances monitoring and shared situational awareness at different nodes in the EXCON area. This view can be tailored to different needs and includes displays such as an issue tracker (in support of monitoring, investigation, and resolving issues found during execution), a status overview of players on the DIS network, and automated rule checks (such as for the identification of anomalies with respect to DIS protocol adherence). The analysis application can be used on various working stations for monitoring, querying, and analysing all logged data.

The back-end of DREAMBOARD's framework consists of a data logger, a database server and a display server. The data logger, that allows for integration with existing tools such as GRACE and JODA uses parallel data capture mechanisms to collect all DIS and Link-16 simulation and connectivity data, and processes these data for storage in the database. The database is a relational SQL database capable of storing time-series data containing geographic objects. The display server acts as bridge between client views in the EXCON organisation and the database. It synchronises and distributes relevant information to the dashboard views (using automated rules for real-time monitoring) and processes queries from the analysis applications. Figure 4 gives an overview of the set-up at JPOW19.

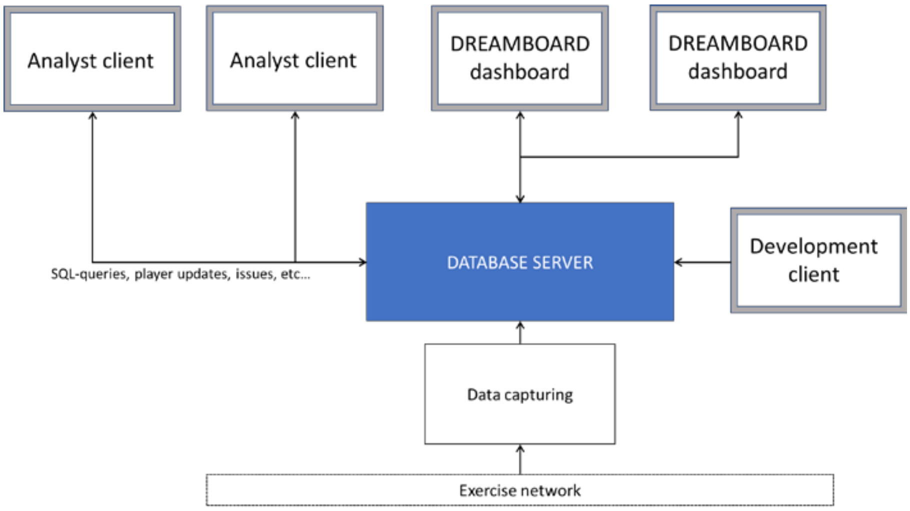

Figure 4: Set-up of DREAMBOARD at JPOW19

During JPOW19 execution, all DIS and Link-16 network traffic was logged using the DREAMBOARD database. Data that could not be recorded included voice communication and operator-system interactions (for example which buttons were clicked). The latter was due to the infrastructural set-up of the exercise. However, it is possible to enable logging these kinds of data in the future. Based on direct user feedback and user requests, additional features were developed onsite, even during the execution phase.

4.3 Extending the EXCON organisation

In support of the introduction of the Integrated Analysis Concept, the adjudication cell in the JPOW EXCON organisation was extended and transformed into an Integrated Analysis Cell. In this cell the analysists could work on dedicated DREAMBOARD analysis stations. In addition, various dashboard functions of DREAMBOARD were displayed at large mission monitoring screens to enhance shared situational awareness in the EXCON areas. To ensure that the analysists could focus on their analysis work, the monitoring of the scenario execution by other JAT-members was done at nearby working locations in the EXCON area. Requests for analysis could be done via multiple ways of communication such as phone, mail, chat, and request for analysis/observation forms. Managing and prioritising analysis requests was a shared tasking between several leads in the EXCON/JAT team. To ensure that stakeholders knew about the novel support offered by the Integrated Analysis Cell various briefings and trainings were given to stakeholders prior and during the JPOW19 execution. Last, but not least, the set-up and introduction of an Integrated Analysis Concept was strongly supported by the AACG lead, the JPOW19 Project Office, and the binational JPOW19 Core Planning Team.

5.0 MAIN RESULTS AND TAKE AWAYS

This paper described the need for advancing analysis methods, tools, and techniques in synthetic battle spaces for IAMD. Next, a first proof of concept for integrated analysis for the IAMD domain in general and for the JPOW exercise series in particular has been presented.

Main requirements for integrating analysis efforts in synthetic battle spaces are:

- the ability to handle large amounts of different types of data;
- the ability to monitor and analyse (near) real-time as well as having the ability to perform post-event (off-line) analysis;
- the ability to compare observations against (M&S) predictions;
- the ability to assess solutions against multiple criteria;
- the ability to synthesise and/or perform meta-analysis;
- the ability to support decision making; and last but not least
- the ability to support (organisational) learning.

The Integrated Analysis Concept that has been developed for JPOW19 required both organisational and technological innovations. In support of the organisational innovation, the organisation and methods of data collection, monitoring and analysis were advanced via the DCAP and led to the introduction of an Integrated Analysis Cell in the EXCON organisation, which could focus not only on the analysis of 'what' happened but also dive into the analysis of 'why' something happened during a specific event. The importance of training and familiarisation with new concepts and tools was highlighted in the feedback received from various stakeholders.

The technological innovations requiring the enhancement of integrated data collection, storage and analysis, were based on a variety of qualitative and quantitative data sources and tooling already in use. This led to the introduction of NATO's JEMM tool in JPOW exercise series, the development of a McJaT database, and to strengthen the already existing monitoring and analysis means via the development of a DREAMBOARD database, an integrated analysis application, and various dashboards for enhancing shared situational awareness in the JPOW EXCON organisation.

Tools such as a MS Access database and SharePoint provide flexible solutions that are relatively easy to develop, manage, and alter during use. However, guaranteed data storage and accessibility of data is crucial for the trustworthiness of any data collection and data storage solution provided. For future JPOWs, the daily and highly time critical qualitative data collection process could be enhanced further by the introduction of electronic data collection tools supporting the JAT observers in their work at any location in the exercise. This calls for digital portable solutions that can be used both in a stand-alone operating mode (accredited for use in a NATO SECRET environment) and an upload/networked mode for entering data into the McJat database.

The familiarisation with JEMM in the JPOW19 EXCON was well received. The main objective for this introduction in JPOW19 was to assess the potential and added value of such a tool suite in the EXCON area during the execution phase. JEMM was mainly used for monitoring the Main Event List/Main Incident List (MEL/MIL), and for keeping track of non-simulated injects in the scenario in support of the Intel Response Cell. The potential of using JEMM also during scenario development prior to execution was clearly identified by the SISCG, as well as the potential of having an interface between PELORUS and JEMM to be able to monitor the scripted simulated injects in the scenario via JEMM as well. Both lines for follow-on developments are currently pursued.

For the DREAMBOARD database, the JODA data capturing mechanisms proved to be very robust. Data capture and storage did not fail once during twenty days of consistent and extensive data logging. This was a crucial enabler and was essential for establishing trust. The ability to handle different types of data, as well as the ability to combine a time scaled (relational) database and a geographical database extension (for retrieving locations) ensured that at any time and location relevant data sets could be integrated for analysis. This was facilitated by automated rules, queries, and logic. Flexible, meaningful, and user-friendly dashboards contributed to the shared situational awareness in the JPOW19 EXCON area. Ongoing developments, based on direct user feedback, were implemented during JPOW19.

The first proof of concept for integrated analysis as fielded and tested in JPOW19 has led to a flexible and robust set of capabilities, which were the combined result of using both existing and new tools, methods and techniques. Due to the highly collaborative and multidisciplinary R&D approach, based on advancements and the combination of novel M&S, technical & operations analysis, and data science methods and techniques, this could be done at relative low cost and low risk. Derived from this first experience, the list of new ideas and requirements to further analysis for synthetic battle spaces in the IAMD domain is quite substantial. To quote some participants on both potential and added value:

'via integrated analysis it is possible to translate zeros and ones into common operator language' and *'via such an approach the investigation, analysis, and common understanding of why certain events in the scenarios played out in the way they did, can be done in a comprehensive manner'.*

After JPOW, the new analysis tools, methods, and data results have been transferred to the IAMD BL of the NLD GBADC in support of future JPOW editions and other BL events. For JPOW21, next to follow-on developments for the toolset, it is important to extend familiarisation and training on integrated analysis to all control groups. Also, the integration of technical and operational analysis can be strengthened further by rethinking the set-up of the Integrated Analysis Cell in the EXCON area.

6.0 WAY AHEAD

The reason why integrated analysis is probably such an appealing concept has likely to do with the fact that it supports the universal human need for sense making in any environment in which they have to operate. However, sense making is easily hampered when having to act and decide in complex mission environments dominated by large amounts of data, such as the battle spaces of the nearby future, in which all military domains - cyber, land, air, maritime, and space - have to be interoperable to deliver synchronised and mutually supporting effects in the human, physical (kinetic), and information dimension.

Integrated analysis will require ongoing developments in terms of (tailored) organisation, methods, tools and technologies to keep up with the high demands of this so called multi-domain-battle space, including military operations and warfares such as operations in contested urban environments (OCUE), littoral operations, and IAMD. This also strongly drives the demands for next generation synthetic battle spaces and their added value by supporting complex sense and decision making by thorough and comprehensive analysis means.

Similar to the challenges for assessing the validity and fitness-for-purpose of large scale simulation integrations, integrated analysis calls for a careful application of investigation, analysis and assessment methods on certain actions, events or anomalies that occur in these battle spaces. This should be done by cross-referencing both the method used and actual outcome (assessment) and is particularly relevant when it concerns a joint analysis and assessment effort. Whilst the orchestration of various analysis means and methods are key to success in joint synthetic battle spaces, this does not necessarily apply to the actual integration of all tools and their specific functions into one collective toolset. By using integration frameworks it is relatively easy to ensure that separate tools can operate together in an orchestrated manner.

From the first proof of concept as described in this paper, it is important to note that strong advancements can be made by using data driven analysis approaches, next to the more commonly used objectives-based data analysis approaches. In particular when combining (novel) M&S, operations & technical analyses, and data science methods & techniques. These findings were confirmed by a post-JPOW data challenge. A one-day hackathon for TNO data scientists, led to the development of novel analysis means and views on the data collected. It was impressive to see how without any domain knowledge, these data scientists were quickly able to come up with novel solutions. In support of these findings, and in support of R&D efforts for joint synthetic battle spaces it is recommended that NATO STO pursues more integrated studies by combining MSG, SAS and HF knowledge and expertise.

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8.0 REFERENCES

[1] Information on Joint Project Optic Windmill: https://www.japcc.org/joint-project-optic-windmill

[2] Distributed Interactive Simulation Committee of the IEEE Computer Society (1998). IEEE Standard for Distributed Interactive Simulation (DIS) - Application Protocols. *IEEE Std 1278.1a-1998*

[3] NATO Standardization Agency. Standardization agreement (STANAG) 4603, modelling And Simulation Architecture Standards For Technical Interoperability: High Level Architecture (HLA).

[4] NATO Standardization Agency. Standardization agreement (STANAG) 5516, tactical data exchange – Link16

[5] Phister, P.W., Jr., Busch, T., & Plonisch, I.G., (1995). Joint Synthetic Battlespace: Cornerstone for Predictive Battlespace Awareness, Air Force Research Laboratory/Information Directorate 26 Electronic Parkway, Rome NY, 13441-4514.

[6] USAF, Joint Synthetic Battle Space for Simulation Based Acquisition, JSB Concept of Operation (CONOPS), 2001.

[7] Kwak, S.D., Andrew, E.B.(2002). “Technical Challenges for Joint Synthetic Battlespace (JSB)”, Proceedings of 2002 Fall Simulation Interoperability Workshop, SISO, Orlando, FL, Sept. 9-13, 2002.

[8A] NATO RTO Task group SAS-034/MSG-001 (2007), Mission Training via Distributed Simulation and First WAVE: Final Report, NATO RTO Technical Report, RTO-TR-SAS-034

[8B] Gehr, S., Schurig, M., Jacobs, L.M.R.A., Pal, J. van der., Bennet, W., & Schreiber, B.T. (2005), Assessing the training potential of MTDS in Exercise First WAVE, NATO RTO-MSG-035 conference on the effectiveness of modelling and simulation, Warsaw, Poland.

[9A] Jacobs, L.R.M.A. (2012). Collectieve Missie Simulatie, eindrapportage onderzoeksprogramma V501. TNO-rapport TNO-DV 2012 A102, TNO Den Haag.

[9B] Lemmers, A.J., Jacobs, L.R.M.A., Karelse, R.J., & Klomp, J.A. (2010). A Collective Mission

Simulation Capability for the Royal Netherlands Armed Forces. In: Proceedings I/ITSEC 2010, Orlando, FL, USA.

[9C] Voogd, J.M., Kraker de, K.J., Jacobs L.R.M.A., Kuiper F., Keuning, M.F.R., and Karelse, R.J. (2008), Collective Mission Simulation in The Netherlands, Key Problems & Solutions, I/ITSEC conference, paper 8002, Orlando, FL, USA.

[10A] Huiskamp, W., (2017). Leaflet on the Mission Training through Distributed Simulation (MTDS) Research Programme (TNO-V1701), TNO Defence, Safety and Security, The Hague, The Netherlands.

[10B] Saltmarsh J., MacKenzie S., The Future of Collective Training: Mission Training through Distributed Simulation, Royal United Services Institutes, UK 2008

[11] Mac Lennan, A., Jacobs, L.R.M.A., et al. (2019). IAMD Battle Lab Study Paper, IAMD Battle Lab Working Group, NLD Ground Based Air Defence Command, Vredepeel, The Netherlands.

[12] Jacobs, L.R.M.A & Ordelmans, P.L.X. (2014). Current and Future Battle Lab Operations at the Dutch Maritime Warfare Centre, MSG133-14, NATO UNCLASSIFIED.

[13] Velde, J.C., van de, (2019). CABL, the CLSK (Royal Netherlands Air Force) Aerospace Battle Lab, leaflet, Air & Space Warfare Centre, Royal Netherlands Air Force, Breda, The Netherlands.

[14] Onzenoort, P.H.G.J.,(2018). The Simulation Battle Lab, innovation via simulation leaflet, JIVC-KIXS, Defence Material Organisation, Utrecht, The Netherlands.

[15] *Missile Defence, an overview* (2007*)*. TNO Handbook. TNO Defence, Security & Safety, The Hague, The Netherlands

[16A] Jacobs, L.R.M.A., Wiel, van der R., Bosch, J.J.M, & Olthoff, W.R.J. (2009), Supporting Collective Training & Thinking in Joint Project Optic Windmill, I/ITSEC Conference, paper 9222, Orlando, FL, USA.

[16B] Stamm, M., Kuipers, E. & Hein, W. (2009). Collective Training - Collective Thinking: Using Innovative Adaptive Simulation in Exercises, I/ITSEC conference, paper 9111, Orlando, FL, USA

[17] Kleef, A., Jacobs, L.R.M.A., Tuin, van de, B.F., & Kroon, I.L., (2011). Exploring Novel Air and Missile Defence Concepts from a Maritime Perspective: The Royal Netherlands Navy's Lessons Learned, TNO, The Hague the Netherlands.

[18] Information on MTMD: http://www.janes.com/article/48106/surface-navy-2015-mtmd-forum-set-for-at-seainteroperability-demonstration

[19A] Meessen, W.R.M.J. & van der Wiel, W.M. (2014), Concept Development & Experimentation, MILITAIRE SPECTATOR, JAARGANG 183, NUMMER 4 – 2014.

[19B] Kass, Richard A., (2010), The logic of warfighting experiments, The Future of Command and Control, ACT/CCRP.

[20] Information on CFBLNET: http://www.disa.mil/CFBLNet and
https://en.wikipedia.org/wiki/Combined_Federated_Battle_Laboratories_Network

[21] Eaton J., Redmayne, J. & Thordsen, M. (2016). *Joint Analysis Handbook (3rd Edition),* NATO Joint Analysis and Lessons Learned Centre, Portugal.

[22] Aires-da-Silva, A., & Maunder, M., (2005). Integrated Assessment. IOTC Proceedings, published on https://iotc.org/sites/default/files/documents/proceedings/2008/wptda/IOTC-2008-WPTDA-PRES15.pdfhttp://www.coastalwiki.org/wiki/Integrated_Assessment

[23] Jeffery, J. (2010). *What is integrated analysis?* Article published online at http://www.hubb.com/TradingTutors/Articles/1675/What-is-Integrated-Analysis.

[24] Curran, P.J., & Hussong, A.M., (2009). Integrative Data Analysis: The Simultaneous Analysis of Multiple Data Sets, University of North Carolina at Chapel Hill. Published in final edited form as: Psychol Methods. 2009 June ; 14(2): 81–100.

[25] https://www.unpri.org/download?ac=312 http://www.sri-connect.com/index.php?option=com_content&view=category&layout=blog&id=22&Itemid=104

[26] Bölker, A., Marinus, J.W., et al. (2017). Final Exercise Report for the JPOW17 edition. JPOW-BPT, Royal Netherlands Army and German Air Force, Vredepeel, The Netherlands.

[27] Bi-SC 75-003, (2013). NATO's Collective Training and Exercise Directive, SHAPE and HQ SACT.

[28] Reinartz, D., et al. (2019). Data Collection and Analysis Plan (DCAP) for JPOW19, JPOW-AACG, Vredepeel, The Netherlands.

[29] *NATO Lessons Learned Handbook*, 4th edition, (2016). NATO Joint Analysis and Lessons Learned Centre, Portugal.

[30] Burns, S., (2015). "*War Gamers Handbook: A Guide for Professional War Gamers",* Newport (RI): US Naval War College; 2015

[31] Wozniak, U., et al. (2019). Report on the Post Exercise Analysis JPOW 19, JPOW-ICG, 10 September 2019, Vredepeel, The Netherlands.

[32] Reinartz, D., et al. (2019). JAT contribution to the JPOW Final Exercise Report, JPOW-AACG, Vredepeel, The Netherlands.

[33] Theunisse, A.C., et al. (2019). Final Exercise Report for the JPOW19 edition. JPOW-BPT, Royal Netherlands Army and German Air Force, Vredepeel, The Netherlands.

[34] Information on PELORUS: https://jessix.com/

[35] Information on JROADS: https://www.tno.nl/nl/aandachtsgebieden/defensie-veiligheid/missions-operations/jroadssimulatie-van-complexe-wapensystemen/
https://www.tno.nl/media/1531/jroads_a43.pdfRef

[36] Witberg, R., Veldhoven, van, E., Keus, D., & Ordelmans. P., (2010). Generic Reconstruction and Analysis for Simulations or Live Exercises. Simulation Interoperability Workshop-010.

[37] Information on NATO ITB: https://www.ncia.nato.int/BMD/Pages/About-us.aspx

[38] Information on TDACS: http://marzen.com/Docs/TDACSOverview.pdf

[39] Information on ADIVS: https://www.peraton.com/adivs-ii-air-defense-interoperability-validation-system/