Data-Driven and Personalized Training as a Service Infrastructure

Enhancing Operational Readiness through Adaptive and Efficient Training Methods

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ABSTRACT

To illustrate the importance of continuous training and maintain the required proficiency level, consider 5th generation air force pilots. These pilots must be able to execute various military missions with rapid deployments, which demands ongoing training. However, today's training is mostly standardized per community and every pilot receives roughly the same training, despite having different learning curves and training needs. As a result, the total training is inefficient, both from a corporate and individual perspective, and does not achieve the best possible operational readiness.

Recent advances in technology, such as artificial intelligence, data science, learning analytics, simulation, x-realities and the internet-of-things, have enabled the implementation of new training strategies, such as performance-based, personalized and adaptive training. These strategies aim to utilize available live and virtual training assets optimally, in order to achieve the highest possible pilot performance in the most efficient manner. The digital era allows us to create a service-oriented training ecosystem, which objectively tracks, analyzes and utilizes training data to offer each individual pilot, on-demand, the training most beneficial to their learning curve.

The concept of data-driven training combined with a service-oriented training provision approach is referred to as Training as a Service (TaaS). In this paper, we elaborate on this concept from a technical perspective, including the required architecture for enabling TaaS. The infrastructure consists of several elements: a training element that controls all training-related parts, including the Mission Environment as a Service (MEaaS) and adaptive scenarios; an analysis suite that performs logging and data analysis; a dashboard to control, manipulate and visualize training; and a training orchestrator as the backbone of the infrastructure. We illustrate this with a concept demonstrator developed by Royal Netherlands Aerospace Centre (Royal NLR), which includes services for training orchestration and scheduling, digital training syllabi, xAPI2 learning lockers, dashboards, learning analytics, cognitive load measurements, and scenario configuration with adaptive Computer Generated Forces (CGF).

ABOUT THE AUTHORS

Guido Tillema works for the Royal NLR as Medior R&D Engineer at the Training and Simulation department. Currently, he is involved with research into new and future training technologies, these include VR/AR/XR, as well as, reduced stroke motion platforms. He completed his Masters in Control & Simulation, with Cum Laude, at the faculty of Aerospace Engineering of the Delft University of Technology, where he specialized in Control & Simulation. His passion for aerospace can also be found back in the work he does for EASA, where he is, on behalf of EASA, a Technical Inspector to perform FSTD evaluations.

Manfred Roza is Senior Scientist at the Royal Netherlands Aerospace Centre NLR. He holds a Ph.D. in aerospace engineering from Delft University of Technology and has more than 25 years of experience in simulation and training, in the academic world, simulator industry, and governmental organizations. His current research activities focus on AR/VR/MR, distributed cloud-based simulation, cross domain security, training eco-systems, and cost-optimization. Furthermore, he is the principle simulation training system consultant for the RNLAF Helicopter Command for the acquisition and deployment of the future AH-64E/CH-47F Multi-Ship Multi-Type Helicopter Simulator Centre and the NH-90 Full Mission Flight Training Centre.

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INTRODUCTION

The Royal Netherlands Air Force (RNLAF) is currently shifting towards a 5th generation way of operating. To assist in this transition, the Royal Netherlands Aerospace Centre (NLR) conducts research in the field of the operability of materials and personnel, and especially the training to ensure an optimal synergy between them and to prepare for emerging complex threats. This shift towards a 5th generation way of operating is seen in the rapid introduction of new 5th generation platforms in the next decade such as the F-35, AH-64 Echo, CH-47 CAAS, NH90 MR1, A330 MRTT, MQ-9 Reaper as well as new sensors and systems for Intelligence, Surveillance and Reconnaissance (ISR), AirC2 and Data Science cells. These new platforms, sensors and systems alter the RNLAF operational paradigm from platform oriented towards strong information-driven or data-centric operations, which in the future will be primarily conducted in multi-domain or combined armed forces settings. A key element here is the net-centric integration and interoperability of a wide range of different operational weapon platforms, sensors, and highly-automated and Specific, Measurable, Attainable, Relevant and Time-bound (SMART) decision-making systems. In this mesh of platforms, sensors, systems and air force personnel there will be a continuous flow of large amounts of operational data and information that must be acquired, processed, and exchanged in real-time to assure adaptiveness and agility to today's fast-changing operational situations. Modelling, simulation, extended realities (XR), artificial intelligence and machine learning methods, techniques and technologies are the underlying engine to share, process and interpret all this data and information in a proper context, and augment the human operator's visualization of the operational picture (Situational Awareness (SA)), predictions, decision making and delivery of the appropriate (non-)kinetic effects.

The role of the RNLAF personnel and their associated competencies will have to shift accordingly to be able to effectively and efficiently operate these new complex and highly automated capabilities within these information-dense and fast-changing operational work environments. This requires a new vision, paradigms, methods, technologies and organization of how training is realized, delivered and managed to ensure an appropriate RNLAF personnel readiness level. Here, one shifts from the classic competency paradigm towards performance & evidence-based training (PBT/EBT), personalized & adaptive training paradigms, which are all rooted in similar information-centric/data-driven and Artificial Intelligence/Machine Learning (AI/ML) intensive concepts or technologies used in the operational domain.

The key concept of future training operations and the life-cycle is that it will provide training - just in time and at the point of need – which is personalized and adapted to the almost instant training needs of the individual air force operator, crew, section, flight or staff level. This requires more distributed training delivery with a blend of various targeted fidelity simulation training devices, serious gaming, mobile and other XR training means in addition to today's classic live training and centralized high-end simulation facilities. On the other hand, an efficient delivery of such training requires common and shared modelling, simulation, scenario and learning content management, instruction, debrief and personalized dashboards, and big-data analysis and AI/ML services provided through an integrated network and military cloud-based operational training capability. Ideally this operational training capability should directly connect with the operational mesh of weapon platforms, sensors and systems to seamlessly synchronize the training and the operational environment, and effectively facilitate mission rehearsal. Moreover, this training capability should be able to capture and analyze the performance and effectiveness of actually executed missions and adapt the training accordingly based on the lessons learned gained from such assessments. Desirably, the data gathered in earlier training sessions combined with the objectives of the upcoming mission should tell which operators are the competent for the specific mission. This is rooted in of what within NLR is referred as the 'holy grail' of future training, a multidisciplinary training ecosystem.

The goal of this research is twofold: 1) performing desk research to establish a vision concerning future training applications and 2) the development of a training ecosystem concept demonstrator. The scope is limited to Technology

Readiness Level (TRL) 4, which means the developed components are tested for in an experimental environment. For Royal NLR, the X-Lab is the designated area to perform this kind of research. Beyond the physical space, the X-Lab houses (research) simulators, computers, XR devices, and other tools to facilitate innovation. Initially, the research was restricted to the use-case of a fighter pilot training, with a focus on Continuation Training. Over time, the scope was enlarged to enable training possibilities beyond fighter simulators. Creating a robust ecosystem, capable of servicing all kinds of training applications, became a goal in itself.

This paper is structured according to these research goals. First the training ecosystem concept is described. Afterwards, the technological infrastructure for realizing this training ecosystem concept is elaborated from a technological standpoint using the experience gained from the development of the concept demonstrator. In the discussion, current (technical) possibilities and limitations are described. Finally, this paper concludes with conclusions and recommendations.

TRAINING ECOSYSTEM

Many professional operations, especially in the military, require complex expertise. Acquiring these proficiencies requires adequate training and once these skills have been taught, it is important that the professional remains competent in these skills in order to be combat ready at any time. Especially in high-risk professions, skill decay is often prevented by refresher training. While the rate of skill decay differs among individuals and types of skill, the current training regime is still based on a rigid schedule. This may result in over-trained skills in some areas and considerable skill decay in other areas (Løhaugen et al., 2020; Toubman et al., 2020; Vlasblom et al., 2020).

Ideally, the re-training occurs just before the skill is about to decay to an undesirable level. Although this comes with practical issues, it is a considerable shift compared to conventional training programs. Acquiring and maintaining these complex skills will be more effective when the training is tailored to the operator. Training must therefore become personalized; adapting to the individual needs of each professional or operator. It is important to mention that skill decay and the limit of undesirable skills levels are influenced by many factors, such as experience, personal factors, task, competency, etc., and therefore requires more research before implementation.

To predict the personal training need, the performance of the operator needs to be tracked. This implies advanced data logging from the training systems as well as advanced tooling for predicting and scheduling the personal training need. Security and privacy requirements were outside the scope of this project, but they are of essence when introducing a training ecosystem into the organization. Simulator data is notoriously known for its large datasets: each and every pedal movement, steering nudge and button press is likely to be registered. Translating this data into a meaningful performance measure can pose quite a challenge.

Performance data can give insight in the current skills, knowledge and attitudes of the professional / operator. It might very well be that a professional is highly proficient in a certain subskill - e.g. controlling an aircraft -, while another subskill - e.g. concerning the tactical performance - is decaying. With this information accessible, the instructor can construct more targeted training. Also, it is expected that the level of experience highly influences the skill gain and decay of the operator. Typically, novelties show major improvements in their trained task as well as large skill decay. For experts, often minor skill decay is observed because of repetitive training throughout their career. This affects the need for exercise within the population of operators considerably.

Besides the performance measures regarding flying and tactical skills, it is also possible to gather data regarding the mental state of the pilot. By using psychophysiological equipment, such as eye trackers, EEG devices or heartrate chest straps, it is possible to detect someone’s attention, fatigue or mental workload. All of these psychophysiological constructs can influence the flying performance, and might therefore be the root-cause of sub-optimal flying performance.

Gathering (performance) data is not enough to facilitate performance-based and adaptive training. The instructor should be supported by the data, without being bothered by too much information. The raw performance data should therefore be filtered, possibly analyzed and presented to the instructor in a way that it can be used during and after the training. Depending on the intelligence of the training system, it could even give a recommendation for the next training. This is what we consider “Training as a Service (TaaS)”. To facilitate TaaS, one requires a training or learning ecosystem. Although there is no consensus on a definition, we use the definition stated by Frederickson Learning: “*A Learning Ecosystem is a network of people, resources, and technology from both inside and outside the organization, all of which have an impact on learning.*” (Lucas, 2016). The terms training ecosystem and learning ecosystem are used interchangeably and are considered the same within the context of this paper. As a result, the usage of a training ecosystem should allow the operators to be trained more effectively and efficiently. Effectively, by better reaching the training goals, and efficiently by achieving the goals in less time. Ultimately this causes the soldier, squadron, or the armed forces as a whole to be more operationally ready.

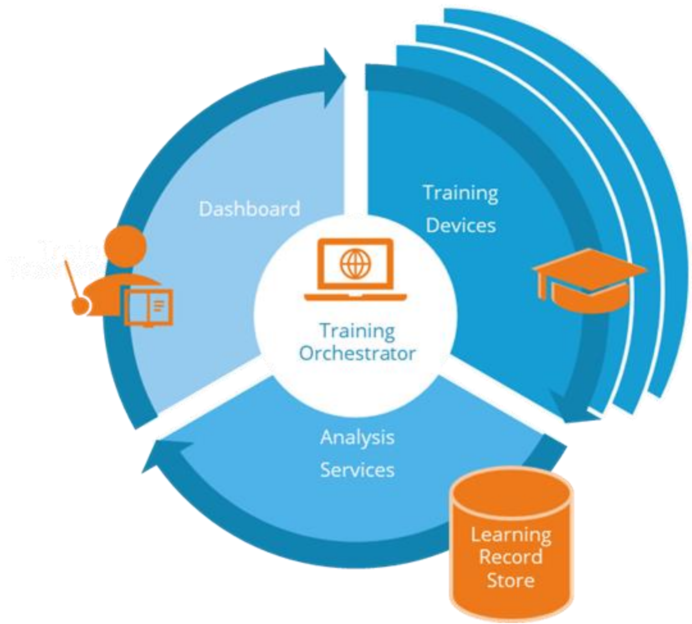

Figure 1 Training ecosystem components

The starting point for the development of the training ecosystem beyond the technical requirements is as follows; support the learner, keep the training content relevant (e.g. scenario, mission environment files and flight simulation models), set up the hardware and software, and interact with the training with operational systems. The latter being related to Live, Virtual, Constructive (LVC) simulation training possibilities, where training scenarios can be performed respectively on actual platforms, in simulators, and with computer-generated forces (blue and red). Currently, our developed training ecosystem only facilitates Virtual and Constructive training possibilities. Nonetheless, training data from Live training, like instructor scores, can be inserted into the training ecosystem via the dashboard by the instructor to allow for comprehensiveness.

Within the training ecosystem, four main components are distinguished; dashboard, training devices, analysis, and the training orchestrator. This is visualized in Figure 1. The dashboard is the central portal where operators, instructors, and higher ranked officers log in to monitor the operational status concerning training. For operators this is the interface which provides information regarding their upcoming training sessions and their training history. After a training is initiated from the dashboard, the appropriate simulator and associated applications and services are started to enable the operator to perform their (part-)task. Within one training, multiple operators and platforms can participate. In addition to multi-ship training, this process must be able to be performed in parallel with other ongoing exercises. During the training, several data streams are logged, analyzed, and stored. For storage a Learning Record Store (LRS) is used to structure data collection of connected systems. Hereafter, the analyzed data and derived information is presented to the operator and instructor, which assist them in the (manual) scoring of the exercise and thus improved recommendations for upcoming training sessions. The entire cycle, which includes starting and stopping the appropriate software/hardware and its services, is monitored and controlled by the Training Orchestrator. The Training Orchestrator can be seen here as backbone of the training ecosystem, which can be hosted on-premises.

To facilitate a training ecosystem which meets the requirements as described above, one needs a flexibly built and services-based infrastructure. To create more flexibility, a shift is demanded from a local to a globally available architecture. This will offer services to customers which operate in a networked instead of on self-contained fixed systems. Examples of such services include hosting the dashboard, databases, and other ecosystem services. This is in line with the Anything as a Service (XaaS) philosophy. The main advantage of service provision instead of locally stored software is the suppliers' flexibility to shorten the innovation cycle and to provide better support. The components will be clarified from a technical perspective in the next section.

TECHNOLOGICAL INFRASTRUCTURE

Previous section focused on the first part of the research goal, the establishment of a vision for future training applications. This section mainly focuses on the second part of the research goal, where this vision is translated into the development of a training ecosystem concept demonstrator. Here, the infrastructure, components and services required for enabling a training ecosystem will be elaborated from a technical perspective. Due to the modular setup of the technical infrastructure architecture, the ecosystem is not limited by the existing simulators, measuring equipment, or services.

As described previously, the training ecosystem can generally be divided into a dashboard, training, analysis, and the training orchestrator, serving as a backbone. Figure 2 illustrates these components augmented with elements present within the technical infrastructure. These elements are elaborated upon in this section. The service that hosts all these elements is elaborated first.

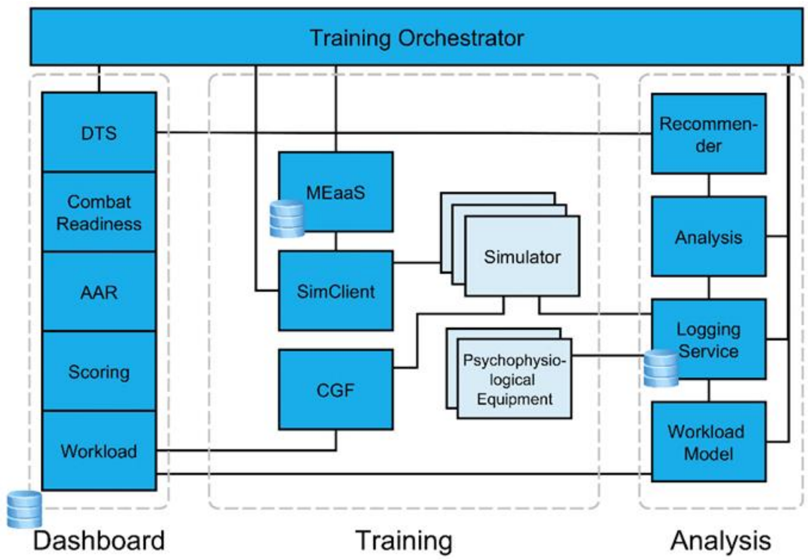

Figure 2 Representation of Training Ecosystem Infrastructure

Hosting

In order to build such a modular, flexible and failsafe system a robust hosting service was required, and Kubernetes was used for this purpose. Kubernetes (Cloud Native Computing Foundation, 2022) is an open-source system for automating development, scaling and management of containerized applications (which are applications that run in isolated runtime environments, meaning separate environments for running software). Kubernetes is used for hosting the developed services and components. The ecosystem is not limited to Kubernetes and any Container-as-a-Service application may be used instead. In essence, Kubernetes is used to manage and host (on-premise) the different jobs that are necessary during an exercise, such as starting the simulators and logging data. Kubernetes has the advantage that it allows the containerized applications to run on various physical machines and allows for automatic control of which applications are running at what times and in what locations. Additionally, it supports scaling and self-healing, which becomes increasingly important for larger ecosystems.

Databases

Various databases are used in the training ecosystem, all of which are hosted by the Kubernetes cluster. These databases are essential for the function of the ecosystem. For different elements, various databases are utilized. First, there exists a database containing all the scenarios that can be used for training. This database functions as a Mission Environment as a Service (MEaaS) solution. Here, the scenarios are stored centrally and can be set up for either individual training or group training. Secondly, a Learning Record Store (LRS) holds analyzed training data and scoring for each operator, used to determine their skill set, next training, and possibly combat readiness. Essentially, an LRS is a database system that stores learning records from all the connected systems, employing the Experience API (or xAPI) standard. Additionally, object storage is used to store all the raw training data, such as performance data, simulator data and psychophysiological measurement data. It is important to note that all this data is stored anonymously and encrypted. Lastly, a user database is used by the dashboard for authorization, authentication and loading corresponding training data.

Training Components

As illustrated schematically in Figure 2, the training part of the training ecosystem consists of three software components (dark blue) and two types of hardware components (light blue). Within this compact training ecosystem, three simulators are utilized. Two desktop simulators and one VR simulator extended with a motion platform for a more immersive training (see Figure 3). These simulators can be used for individual exercises but also group exercises. Each of the simulators contains a program that checks if the simulator is available. If that is case, a training can be started and this program downloads the scenario from the MEaaS database and configures everything accordingly. This program is referred to as the Sim Client. This Sim Client is used to utilize (older) simulators and make these available as a service, i.e. Simulator as a Service. The ecosystem is configured in a modular fashion, meaning that it can easily be extended with more simulators, e.g. by installing this Sim Client so that it will be automatically recognized for training. In the future this training ecosystem may even be extended to include live entities, enabling LVC. However, currently, the developed training ecosystem only facilitates Virtual and Constructive training.

Figure 3 Motion Based VR Simulator

To enable constructive training capabilities in the simulation, a Computer Generated Forces (CGF) system is used, consisting of two software applications: a light-weight air combat simulation for aircraft simulation (LWACS) and Smart Bandits. Smart Bandits, an AI solution, models the behaviour of CGF entities, such as friendly or opposing aircraft (Toubman, 2020). Smart Bandits is programmed according to dynamic scripting, enabling complex behaviours for more realistic training scenarios. The two applications combined offer CGFs as a Service, where individual simulated threats or friendly units can be introduced into the training ecosystem using the Distributed Interactive Simulation (DIS) standard, enabling realistic training scenario for a wide range of simulators. Additionally, the CGF system allows for adaptive training scenarios where the CGFs can be manipulated for instructional purposes by either an instructor or an automated system. For example, CGFs can be added or removed during training manually via the dashboard. Alternatively, this adaptation can be automated based on trainee measurements, such as the cognitive load obtained from psychophysiological measurements and analysed by advanced algorithms or AI. For instance, based on high or low cognitive load, the amount of CGF threats can be respectively decreased or increased.

Analysis Components

Within the training ecosystem, an analysis and measurement suite has been set up. This suite is twofold: firstly services are developed to collect, log and store measurement data; secondly, services are developed to process, analyze and correlate this data. With the measurement services, it is possible to acquire relevant data as outlined in the previous section. This data includes training-related performance data, such as whether the operator achieving the different training objectives. Also, simulator data can be obtained, such as the inputs the operator is giving. Finally, psychophysiological measurements can be obtained, including heart rate, EEG and eye-tracking. These services are controlled by the training orchestrator via their APIs and stored centrally in one of the databases.

All this data is then analyzed through different analysis services, such as the Performance Evaluation Tracking System (PETS), developed by the Air Force Research Laboratory (AFRL) (Schreiber et al., 2003), to determine a pilot's performance in air combat missions. Additionally, a service has been developed to determine the operator's cognitive load based on psychophysiological data, specifically EEG (see Figure 4).

A future service for determining pilot performance might involve an AI agent that runs simulations with the same data, testing a wide range of tactics to identify optimal pilot actions. In doing so, it would identify deviations from optimal pilot in the data and bring them to the instructor's attention. Using these deviations and training performance as a basis, the service may suggest at what level each competency or skill was demonstrated by each individual. The instructor can review and correct this data, which would update the individual competence profile, retention interval, skill decay and skill set.

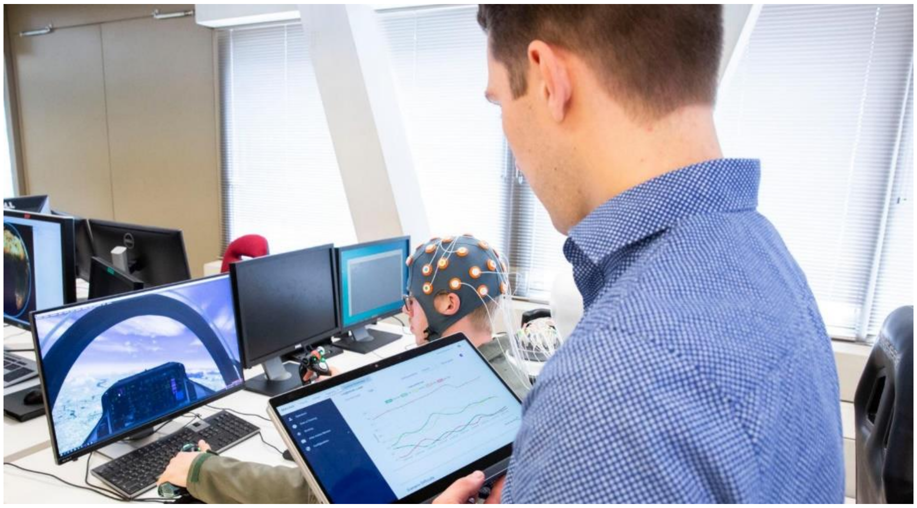

Figure 4 Desktop simulator controlled with operator that is wearing an EEG to measure cognitive load, which is visualized to the instructor

Dashboard

The dashboard is the main interface for operators and instructors to interact with the training ecosystem. Here, training can be designed, selected, started, adapted (in real-time) and stopped. Additionally, the dashboard allows for tracking progress along the performance indicators and competences for a particular training. Moreover, it suggests the next training based on past training results, the current skill set and skill decay.

The dashboard is developed as a web application that can be accessed anywhere and on different platforms (e.g. mobile, tablet, laptop). Upon accessing the dashboard, users are prompted with a login screen. Currently, users are logged in as either an operator or instructor, depending on their role. This data is stored in the user database as described in the previous section. Once logged in as an operator, users receive an overview of their current skill set, progress on competences, retention intervals, and skill decay rate. Moreover, users can review past trainings, including scores and feedback. With this information, operators can schedule new training sessions that stimulate the required competences. If logged in as an instructor, they can view operators' skill sets and access the scheduling tool. In this role, instructors have the ability to schedule for an entire squadron. Additionally, instructors can access more sections within the dashboard that are not visible to operators. These sections include a scheduling tool, digital training syllabus developer tool, training section, and combat readiness section.

Currently, only two roles are available: operators and instructors. This can be expanded with additional roles, such as higher ranked officers, combat planner, etc., with each their own unique functionalities.

Scheduling Tool

In the training ecosystem concept demonstrator, a scheduling tool with basic scheduling functionality is implemented. In the future, this tool would be able to suggest mission types, training devices (e.g. simulators or live training), pairing options for collaborative training based on individual training needs and the achievable training in that mission. It would also be possible to include upcoming currency requirements, minimum intervals between certain training events or upcoming combat missions. It goes without saying that the schedulers have the authority to overrule the suggested schedule. After deployments in low threat environments with limited mission exposure variety, pilots may exhibit skill decay in specific skills and competences. The scheduling tool would optimize training for these individuals, aiming to bring them back to the required levels in the shortest time with minimal effort. Due to individualized skill decay rates and retention intervals, one pilot might accrue more flying, simulator, or academic hours compared to other pilots. This would be beneficial to the overall readiness level of a squadron or unit and should not be abused to lower the total cost (flying hours) of a combat-ready squadron.

The available options in the scheduling tool would vary based on different user roles. When logged in as an operator, individuals can plan and accept training options. Conversely, when logged in as an instructor, scheduling for an entire squadron or group is possible.

Digital Training Syllabus Developer Tool

The next section in the dashboard is the Digital Training Syllabus (DTS), which is a flexible and digitalized version of a normal syllabus. Here, the instructor can efficiently design a syllabus or training blueprint along with corresponding sorties. Additionally, for a given syllabus, the instructor can include all the associated competences that are covered in that syllabus. Then, for each sortie, the instructor can incorporate various training tasks, competences, and link them to the corresponding performance indicators. Essentially, these performance indicators will be used during training to evaluate and score the operator. By scoring these indicators, the individuals competencies and skill set will be updated. Additionally, the instructor can introduce complexity factors to a sortie, such as, weather conditions and degraded systems. In the future it should also be possible to specify which sortie(s) can be performed in a particular training scenario. If then multiple sorties are selected for a particular scenario, cooperative training can be considered, where each individual has their own training objectives while participating in the same scenario. This optimizes the availability of instructors, equipment and supporting personnel.

Training Section

In the training section, the instructor can access various pages. The initial page is an overview of all operators that correspond to the instructor. Here, is the option to select an individual operator and view their progress and skill set, including competences, retention intervals and skill decay. This page essentially functions as an interface for the LRS, incorporating an analysis of the operator's progress and development. Currently, the operator has to determine on their own what the best next training would be. A recommendation engine, like the one proposed by NLR researchers, that aids the instructor in selecting the next training based on operator progress, would be a valuable addition to the training ecosystem (Thijssen & Bosma, 2022). Subsequent pages are more focused on runtime training management, allowing the instructor to manage, monitor and adjust the training execution. There is also a page to initiate a training and obtain an overview of current active ongoing training session(s). Upon initiating a new training, the instructor is prompted with a form, where they need to specify the syllabus and sortie. Depending on the selected sortie, different training scenarios can be activated. Then, the instructor needs to specify the operator(s) and the simulator(s) to be used. Moreover, the instructor can enable various services, like automated CGF using cognitive load, logging for After Action Review (AAR), and more. Upon pressing 'start' the selected training devices are initiated and scenarios are loaded. As described in previous section, the Sim Client is used to ascertain the availability of a training device and to load and configure a scenario.

Within the active training list, it is possible to view the training detail page for all training sessions. On this page it is possible to examine all the training details, such as real-time operator performance, the status of different training objectives, and even a visualization of the operator's cognitive load (if selected). Additionally, it would be possible to score the operator during the exercise based on subjective observation or mark specific events for the AAR. Lastly, it is possible to adapt the scenario in real-time by manually or automatically controlling the CGF entities.

Another item in this section is the scoring page. As previously mentioned, the instructor can score the operator during the exercise. Yet, it is also possible to score the operator after the training is completed using this scoring page. On the scoring page, the instructor rates the performance indicators that are selected in the sortie (as explained in previous section). Scoring these indicators, will result in an update of the skill set (including retention intervals and skill decay). Currently not implemented, is a suggested scoring by the system using the recorded data. This may be accomplished with an AI agent which is running against the same data to determine optimum behavior. In this way, it would recognize deviations from this optimum behavior. Based on these deviations and training end result, the system might suggest a rating for the different performance indicators. It is important to note that this may be possible for some competences, such as ‘flying’, but not for less technical or non-technical skills (NOTECHS), such as ‘leadership’. Also, it should be mentioned that this is not to replace the instructor, but rather to assist.

Finally, there is the option to conduct AAR. When activating the AAR of a specific training, the entire recording is loaded including the marked events. This is achieved with dedicated services that load all necessary data from the databases, along with services that replay the data. This data can be replayed on either a dedicated simulator or via the dashboard where it can be accessed from any location and across various platforms (see Figure 5).

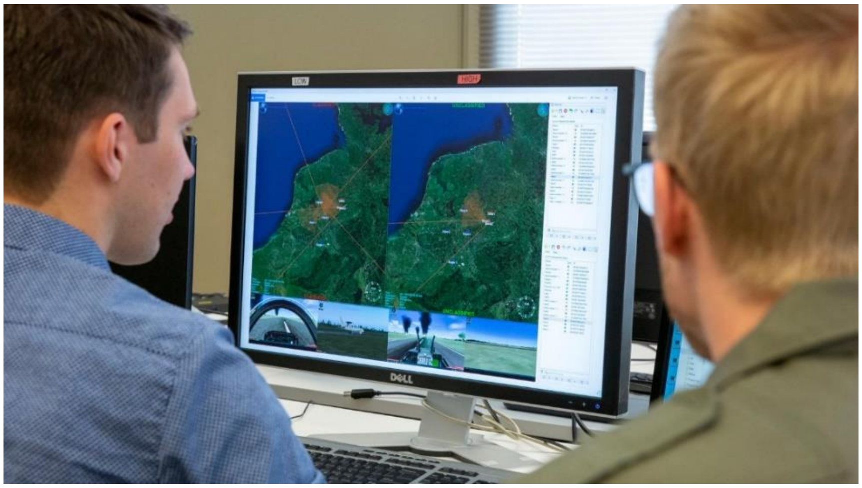

Figure 5 After Action Review impression

Combat Readiness Section
The last section in the dashboard focuses on analyzing the combat readiness of a squadron and identify personnel (such as fighter pilots) who are best suited for upcoming missions based on specified criteria. In this section, you can define the mission’s target date and the required number of personnel. You can also specify the needed competences, complexities and training tasks for the mission. A dedicated service would then search through the databases, examine planned training, past retention intervals, skill decay rates and learning curves to determine which personnel are most qualified for the mission by the target date.

Currently, this concept of combat readiness is in its early stages due to factors such as the availability of reliable data, learning analytics, and a scheduling tool.

Training Orchestrator
The training orchestrator as the central hub of this training ecosystem, integrating all the earlier components and providing a single interface for initiating, controlling and stopping a training session. Also, the training orchestrator service is hosted in Kubernetes. The training orchestrator monitors the state of each training and starts/stops the individual components when needed, such as activating analysis processes after a training is completed. As previously mentioned, the training orchestrator provides a single interface to select a (group) exercise, via the dashboard. After selection, it requests a scenario from MEaaS and starts the corresponding chosen simulators. Additionally, it configures essential measurement tools automatically, including performance logging and analysis services. Furthermore, it enables adaptive scenarios by adding, altering or removing CGF entities, thereby adjusting the complexity of an exercise. This can be controlled manually, as well as, automatically by using one of the psychophysiological measurements or operator’s performance. The training orchestrator also starts the data logging services as well the analysis services during and after a training. Similarly, the AAR can automatically be loaded with a recording from the chosen training session using dedicated services.

DISCUSSION

In this paper the different elements that are involved in PBT regarding refresher / Continuation Training and the required technical infrastructure are discussed. While the fighter community is taken as an example, the principles of PBT and the necessary technical infrastructure hold true for all pilot communities, as well as other MOD communities and even other training applications requiring continuous monitoring of the skill set.

Technological advancements over the past decade, including Artificial Intelligence (AI), data science, learning analytics, and the Internet of Things (IoT), have paved the way for the implementation of new training strategies like PBT. The goal is to utilize the available training resources (such as flying hours, simulator hours and individual man-hours) optimally to achieve the highest possible performance in the most efficient and effective manner, all within the given constraints. The result of PBT is the organizational level of readiness as defined by the organization, and the achievement of personal top performance. This is beneficial to the overall readiness level but should not be abused to lower to total cost, e.g. lower flying hours of a combat ready squadron.

Full implementation of the training ecosystem and underlying PBT concept will require changes and modernization of the training system, and achieving this in a short time frame would be very ambitious, if not impossible. Currently, data gathering and corresponding learning analytics, e.g. for psychophysiological measurements, are still under exploration. Also, this way of training would involve a culture change, which takes time in a community. The following results are foreseen for different timeframes, e.g. considering the air force community as a starting point.

- Short term – Standardization & Digitalization: PBT will focus on developing personalized dashboards integrated with a Digital Training Syllabus (DTS) and subjective assessment. These assessments will rely on instructor evaluations, offering insights into individual training needs, laying the groundwork for combat readiness insights, all by using the insights from this data-driven and personalized TaaS infrastructure.
- Medium term – Learning Analytics & Automation: The focus will turn to creating standardized tools and methods for PBT. This involves automated scheduling based on both subjective and objective data, as well as, external factors, such as upcoming currencies, minimum intervals between training events and upcoming combat missions. The main goal remains to provide personalized training and a carefully planned schedule that supports combat readiness. The inclusion of a recommendation engine which integrates with an automated scheduling tool is expected to bring valuable advantages.
- Long term – Expansion: The goal is to expand the adaption of PBT standards and tools across broader domains, both within the RNLAF and the MoD. This expansion seeks to optimize and align training cycles while fine-tuning large-scale exercises to bolster combat readiness. This long-term vision entails integrating PBT methodologies into various training context to ensure a higher level of operational readiness across different military branches and operations.

CONCLUSION & RECOMMENDATIONS

As stated, the pursued research goals are twofold: 1) performing desk research to establish a vision concerning future training applications and 2) the development of a training ecosystem concept demonstrator.
First, the characteristics and capabilities of what is considered a training ecosystem are framed, namely *a network of people, resources, and technology from both inside and outside the organization, all of which have an impact on learning* (Lucas, 2016). In order to provide personalized and adaptive training, one has to set up a data collection infrastructure to enable storage, sorting, combining and analyzing the data. The usage of multiple data sources (simulators, psychophysiological equipment, instructors grading, etc.) requires flexibility of the technical architecture. This is achieved by the development of all kinds of services which are managed and controlled by the training orchestrator. This is in line with the Anything as a Service (XaaS) philosophy, which instead of locally running software aims for a globally available service. XaaS enables the supplier to be more flexible and to shorten the innovation cycle.
Second, the training ecosystem architecture is designed and built. Each developed software element fits within one of the following components; the dashboard, training devices, analysis, and the training orchestrator. In order to build a modular, flexible and failsafe system, Kubernetes is used as a hosting service. Within this hosting service, different databases and many services (e.g. measurement, analysis, CGF, etc.) are developed. This resulted in the flexible and modular training ecosystem along the TaaS concept.

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