Towards a Methodology for Training & Simulation Capability Rationalization and Valuation

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ABSTRACT

For many reasons armed forces around the world revert to a diverse mix of live, virtual and constructive simulation devices as their prime technology for training. As such an armed force's simulation capability becomes the major cost-driver in military training programs. Many address this by an increased deployment of commercial and military off-the-shelf immersive devices such as virtual, augmented and mixed reality. Another way to deal with simulation costs is the M&S as a Service paradigm. However, most armed forces still struggle to gain a better insight and grip on the life-cycle costs and benefits of their training & simulation capabilities. Returning key questions are: what is the best value portfolio of simulation training devices for our investments? How to make this capability highly sustainable, robust, and agile?

This paper presents the foundations for a rationalization and valuation methodology to support any armed forces in developing, evolving and managing their future training & simulation capabilities in a cost-effective manner. These foundations gradually grew in a range of projects for the Royal Netherlands Air-Force and the Swiss Armed Forces, and also build upon visions from various NATO task groups. The methodology aims to align the training & simulation capability with armed forces' operational and business management goals. It uses a corporate level training needs analysis to gain insight in the armed forces wide training needs, and provides portfolio design guidelines. A valuation framework is deployed to support the assessment of the simulation training devices and underlying simulation capability infrastructure, resources and organization in three key areas: training value, technical quality, and cost. The latter two are rooted in a maturity and life-cycle cost estimate model, respectively, whose major aspects will be highlighted in this paper.

ABOUT THE AUTHORS

Dr. 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 the development, application, and validation of simulation training, both in the academic world, simulator industry, and governmental organizations. His current activities focus on AR/VR/MR technologies, distributed and cloud-based simulation technologies, cross domain security, training simulation eco-system design, and cost-optimization.

Dr. Jelke van der Pal is Senior Scientist at the Royal Netherlands Aerospace Centre NLR. After obtaining a Ph.D. in educational science from Twente University of Technology he has been active in the aviation training R&D, focusing on improving the training design cycle for competency based training and personalized training, often in projects for the Royal Netherlands Air-Force, but also for industry and in international collaborations (NATO and EU funded projects). Currently, he is working towards modelling of retention within the scope of personalized training.

Dr. Michel van Eenige graduated in operations research/econometrics from Erasmus University Rotterdam and obtained his Ph.D. in Mathematics from Eindhoven University of Technology. He joined the Royal Netherlands Aerospace Centre NLR in 1996 and is currently working as Senior R&D Engineer at the Environment and Policy Support department. His research and professional interests are focused on applications of operations research and systems technology in decision-support systems for integrated performance analysis in air transport.

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INTRODUCTION

Military training systems are inherently complex and expensive. Historically, the prime goal has always been to provide effective training in an efficient way, or more specifically, to achieve and maintain mission readiness, with minimal resources, with minimal time, and at the lowest costs. What this exactly means differs considerably between organizations and departments within armed forces. Consequently, achieving the goal implies a battle of the armed forces' stakeholders, each trying to maximize their own interests. These stakeholders include employees of a training school, a training facility, an operational unit, a procurement office and higher military staff offices. They work with different languages, processes and goals, and sometimes employ a rigorous and data-driven method. However, they most often take their decisions independently based on subjective perspectives. The bottom line is that they do not fully understand each other and, while maximizing their own goals, they tend to compete instead of collaborate with each other. In many armed forces, this has resulted in training and simulation landscapes that can be characterized as a collection of stove-piped training solutions that work as stand-alone systems at fixed locations with no or very limited integration and interoperability with each other or with operational systems. As is known from game theory, this leads to so-called winners and losers, but more importantly, the overall result is considerably lower than in a joint effort and collaborative system.

The ineffectiveness of the total military training system is getting unworkable with new demands and changes on the horizon. A good summary of U.S. perspectives and initiatives is provided by Raybourn, Schatz, Vogel-Walcutt, and Vierling (2017). To mention a few: a more flexible workforce is required to respond to the faster changes in military systems and the operational battle field; more personalized training is expected; more data-driven decisions are expected; new attractive training technologies need to be integrated into the system; and the reducing effectiveness of live training rapidly leads to a more central and different role of simulation. Meeting any of these demands and changes already has a disruptive effect on the current way of working, but trying to achieve all of them might turn into an organizational nightmare. Alternatively, the current organization may actively and successfully oppose to these demands and changes. As both options are undesirable, bold measures need to be taken on various levels; certainly at organizational, methodological, and procedural level. In order to migrate to a future training and simulation capability that provides optimal value to the entire armed forces enterprise, it is vital to start with a methodological approach to support the rationalization and valuation of today's disparate training assets.

The rationalization and valuation methodology presented in this paper gradually grew in a range of projects supporting the Royal Netherlands Air-Force (RNLAF), Dutch Defense Material Organization (DMO) and the Swiss Armed Forces (SAF), and builds upon discussions and visions exchanged within a range of NATO task groups. The paper gives insight in the overall methodology and highlights the most essential and major aspects of it. It is beyond the scope of this paper to present the methodology to its full extent. The methodology is still under development and hence, not fully mature yet. It needs to be tailored to the scope and options of the particular armed forces organization.

RATIONALIZATION AND VALUATION METHODOLOGY OVERVIEW

The training & simulation (T&S) capability rationalization and valuation methodology under development at NLR consists of five major building blocks (See Figure 1): a rationalization process activity model, a corporate training needs analysis (TNA) method, a capability options design method, a valuation framework and a smart data eco-system. The rationalization process activity model is the heart of the methodology and is rooted in a well-defined set of training and simulation capability optimization and cost avoidance strategies.

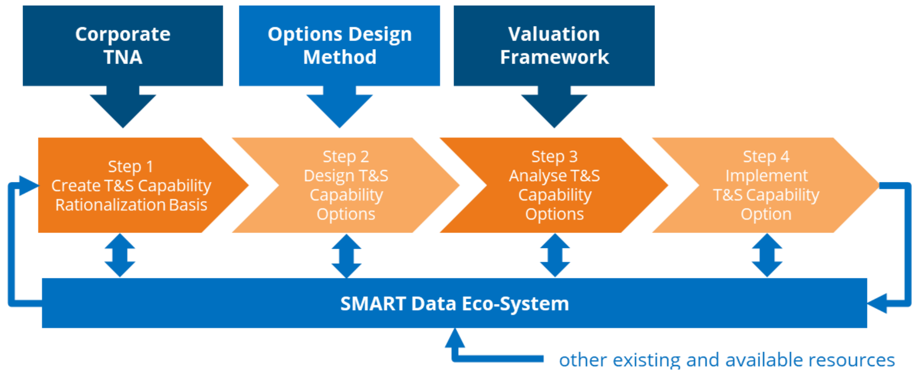


Figure 1 Training & Simulation Capability Rationalization and Valuation Methodology Overview

Training & Simulation Capability Optimization and Cost Avoidance Strategies

The underlying strategy of this methodology is balancing training value and training costs, while recognizing that the total training system cost is the most determining and decisive factor for shaping the future of the armed forces' training and simulation capabilities. Often, a considerable need for cost reduction is expressed. Therefore, the capability rationalization is approached as a multi-modal cost avoidance and benefit optimization problem, where the goal is to find the best possible training and simulation capability alternatives that minimize the all-inclusive training cost of an armed forces organization. Preferably, the alternative(s) should result in a higher and more tangible return on investment (RoI), while satisfying the following set of boundary conditions and practical constraints for an alternative to be acceptable to the armed forces:

1. A minimal set of readiness levels for military personnel must be attainable;
2. A minimal training audience size, composition and time frame(s) must be accommodated;
3. A minimal set of foreseen future operational deployments must be trainable;
4. High sustainability, robustness and agility of the capability must be assured.

These boundary conditions and practical constraints express the actual value to be gained from the revised training & simulation capability. Therefore, these value indicators form also the important effectiveness criteria for the RoI trade-off and selection between possible different alternatives.

Avoiding training and simulation costs requires a cost function. The start point for this cost function is the total cost of ownership (TCO) of a training system which comprises the sum of four cost elements:

1. Initial investments – training system procurement costs, training curriculum and courseware costs;
2. Operational cost – cost to conduct training with the system (e.g. staff, facilities, consumables and logistics);
3. Sustainment cost – cost to support and maintain the system (e.g. personnel, spares, licenses and updates);
4. Decommission cost – cost related to decommissioning training system.

The total cost function for an armed forces training & simulation capability ($TCO_{capability}$) is now defined as:

$$TCO_{capability} = TCO_{cost\_field} + TCO_{cost\_sim\_based} + TCO_{cost\_other\_means} + TCO_{cost\_corporate} \quad (1)$$

Where, TCO_{cost_field} are the cost for the total set of real-life field training exercises, with or without synthetic tools enhancements (i.e. live simulation). $TCO_{cost\_sim\_based}$ are cost incurred from training with all armed forces' virtual and constructive simulation systems (i.e. simulators). $TCO_{cost\_other\_means}$ are the cost from training with the set of all other training means that do not have a direct simulation component, such as often used in classroom training.

$TCO_{cost\_corporate}$ are all cost incurred from running the training organization such as staff level management and other overhead costs. However, for this rationalization and valuation methodology the $TCO_{capability}$ cost function is reduced to only field and simulation-based training costs. Cost of other training means is assumed less significant and corporate costs are assumed to be an invariant factor. Within the TCO of each training simulation device the decommission cost is neglected because these are assumed negligible small compared to the other cost elements. To minimize the $TCO_{capability}$ cost-function within the previously defined boundary conditions and practical constraints, application of future training & simulation methodologies and technologies is expected to generate both enhanced training value as well as cost avoidance. Specifically, the following four core strategies are advised:

1. Transferring live (simulation) training to virtual (simulation) training as much as possible. Live training operational and maintenance costs are in general much higher than those of virtual simulation training.
2. Specifying the optimal blend of simulator types for accomplishing all training goals of armed forces functions over its entire career. This means determining the right set of one or more (i.e. blended learning) simulator types to be used for each function and training time spent on them by a trainee.
3. Establishing synergy and coherence among all training simulation devices used within the whole armed forces. This will result in an organization wide delivery and re-use of shared training and simulation services, tools, scenarios, models and data that are standardized, interoperable, integrated and modular.
4. Applying performance-based personalized training and Artificial Intelligence (AI) intensive automation for training of all functions. Instead of one-size-fits-all training for all trainees in the forces, training is adapted to the actual training needs and progression of the individual throughout the training and their operational career.

These strategies are rooted in the perception that training concepts that have been promising for decades (but often not applied) are now getting enabled by technological advances especially in AI, data science, and low barrier (e.g. commercial off-the-shelf (COTS)) training simulation devices. However, local technical implementations may be unnecessary expensive and not future proof. An integral and joint vision on operations, training and simulation from a corporate level is pivotal for the successful realization, sustainment, and management of a cost-effective future training and simulation capability.

Rationalization Process Model and Application

The previously discussed T&S capability optimization and cost-avoidance strategies have been translated into the methodology's four-step rationalization process activity model as depicted in Figure 1 with the orange arrows. Although presented as a classic waterfall process for comprehensibility, the actual approach is conducted in an iterative manner to manage, mature, and continuously evolve the capability over time to meet the actual armed forces corporate level training needs. The same process is also applicable to an individual service, training school, operational unit, and even a specific training tool, but the wider the application the better. Here, it is essential to consider the national ambition level for its defense system, readiness level, operational goals, and full training pipeline (from initial qualification training up to and including continuation training) for making major strategic decisions about its training system. For this purpose, the proposed rationalization and valuation methodology provides a systematic approach, which is scalable and tailorable.

In the remainder of the paper each process step is presented in more detail in terms of its underlying activities as well as its basic building blocks, methods, techniques and guidelines.

CREATE A RATIONALIZATION BASIS

The rationalization basis embodies three key factors that drive proper training system specification, deployment and sustainment: the real training needs and vision; the military operations, weapon and C2 systems; and the available technology. All three must be considered in conjunction and balanced against each other for establishing an effective and efficient training and simulation capability. This results in a capability which is future proof in terms of being better to maintain and able to respond properly, rapidly and with lesser expenses to military operational and technological changes and innovations over time compared to today's capability. This directly implies that establishing a rationalization basis is a recurrent, or, even better, a continuous activity (Figure 1).

Technology Scan & Training Trend Analysis

Ensuring decision makers are aware of the latest and prospective developments in training, simulation, and supporting technologies is most important to prepare for future-proof and robust training and simulation capabilities. It is important to understand which innovations and developments are heading towards higher training and simulation capability maturity levels. It is equally important to havea realistic insight in which simulation and other digital technologies are enabling which modern training concepts or goals effectively and efficiently. Therefore, a technology scan and trend analysis into training and simulation innovations, trends and technologies are essential to be able to develop a vision on what the future armed forces military training simulation landscape could look like. These also serve as a benchmark for designing and valuating new capability options. These activities consist of systematically capturing, analyzing, integrating and consolidating useful scientific and technical information as well as innovations susceptible to creating strategic opportunities for a highly sustainable training and simulation capability with the right training outcomes. In this, both internal and external resources should be consulted ranging from (inter)national subject matter experts, simulator industry, to available technical and scientific publications and standards.

Today's key training trends include a) the evolution of competency based training, performance based training and personalized training, b) blended learning and balancing training devices, and c) maturing learning analytics. These are empowered by major progress in technologies such as immersive simulation devices (Augmented Reality, Virtual Reality, Mixed Reality), data sciences, artificial intelligence, and mesh networks that allow the interconnection and interoperation of virtually any kind of training simulation device (real live system, virtual or constructive simulator, or any other digital system). These trends are often not purely technological or training methodological, but are closely related.

Corporate Training Needs Analysis

A structural transformation of the training system requires a good understanding of the structural needs of a training organization and is realized by a corporate TNA (C-TNA). Like any other training needs analysis, the C-TNA starts with identifying the overall operational goal. Which tasks, which missions are foreseen in the future and what is the nation's ambition level operationally? Which weapon platforms will be obsolete and which may be acquired in the future? From there, an overview and high level assessment of the current training system are established. Site visits to major training facilities may be scheduled as well as interviews with training managers and operational personnel, including instructors. This usually generates a list of issues ranging from training gaps, technical issues, organizational issues, to budgetary issues.

A C-TNA, as conducted as part of a global rationalization methodology, cannot provide for detailed training needs analysis of all individual military functions. Therefore, the new training simulation capability options are based on groups of functions with an assumed compatible competency profile. For a C-TNA, three global military function categories have been identified for all military personnel that require training:

1. System operators – focus on operating any military system serving tactical goals, from vehicle handling, to (small-arms) weapons and sensor systems (e.g. tank driver, gunner, pilot, radar operator, and foot soldier);
2. Tactical team leaders & commanders – focus on tactical planning, decision making, and C2 systems (e.g. tank commander, navy helicopter tactical officer, air mission commander, group and company commander);
3. Operational commanders & staff - focus on operational planning, common operational picture, and C2 systems (e.g. battalion, brigade and air operations center commanders & staff).

While very broad, as there are considerable differences in specific training needs between functions within each category, this classification is instrumental for outlining a global training and simulation vision and providing rough cost avoidance estimates for a set of envisioned training options.

Creating a Training & Simulation Vision

To effectively accomplish the identified corporate training needs and business objectives, a training and simulation vision must be constructed by applying the selected modern (including maturing) technologies and methods. Such vision is best formulated from scratch. The disruptive changes in the human workforce and the operational demands and constraints in the operational systems require equally disruptive training technologies and approaches. In fact, from the perspective of a vision, they function as balance-restoring instead of being disruptive. A vision puts one in control of the technologies instead of letting technology disrupt your organization unprepared for. A roadmap towards implementation may be evolutionary, cautious (avoiding negative training), and constrained-based, but the vision must remain uncompromised in this process. A range of state-of–the-art elements has been identified (Figure 2), as a basis for shaping a future training and simulation capability vision. These elements have been developed over the years by the wider training and simulation R&D community. Important to mention here is that the three levels of elements (viz. the simulation training device portfolio options, the training methods, and the simulation infrastructure) have to fit in the total vision in order to construct a coherent, integrated and data-driven capability.

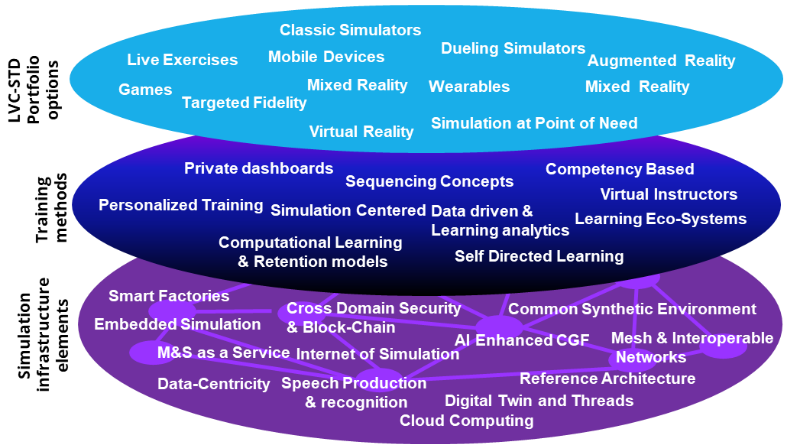


Figure 2 Training & Simulation Vision Reusable Elements

DESIGN CAPABILIY OPTIONS

Once the rationalization basis has been established, the next step is to design a set of possible but viable options for a future training and simulation capability that meets the corporate level training needs and vision, while incorporating the technological trends. This capability design process consists of three steps as depicted in Figure 3.

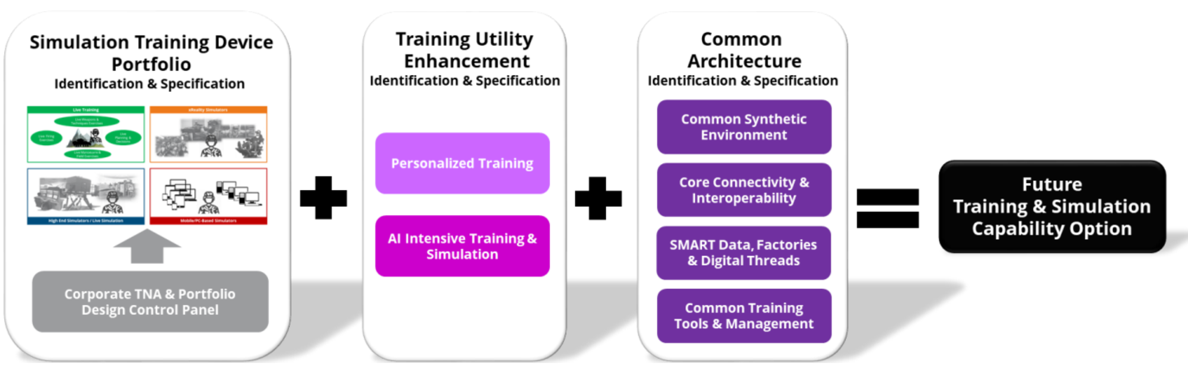


Figure 3 Future Training and Simulation Capability Design Approach

The first step is the identification and specification of alternative simulation training device (STD) portfolio's based on the C-TNA outcomes and using NLR's Simulation Training Device Portfolio Design Process and Control Panel (Figure 4). Next, specific training utility enhancements are identified and specified in the form of shared AI intensive and personalized training capabilities. Finally, the common architectural denominators are identified to obtain a coherent set of elements, resulting in a more efficient, robust, agile, and highly sustainable training and simulation capability than when only the portfolio is redesigned.

Simulation Training Device Portfolio Identification and Specification

Simulation training devices come in many forms as well as levels of fidelity, complexity and prices, and are delivered by numerous vendors. Identifying and cataloguing all these specific forms as a basis for specifying a STD portfolio, are far beyond the objective of an overall training and simulation capability rationalization methodology.

Instead, this rationalization methodology uses the following four major distinct and representative categories to specify a composition of a STD portfolio (Figure 3):

1. <u>Live Training Devices (green)</u> – Real-life field exercises with real weapon systems with role-played scenarios, with or without support of simulation technology or other digital based training technologies;
2. <u>High End Simulation Devices (blue)</u> – Large and life-like simulators (e.g. life-sized mockups, wide screen visuals, real equipment parts and motion systems), often custom made for the specific weapon system;
3. <u>xReality Simulation Devices (orange)</u> – Small, often also wearable, and VR/AR/MR based simulators, using COTS / MOTS simulation and cueing technologies;
4. <u>Mobile/PC-based Simulation Devices (red)</u> – Low-cost simulators that are built upon mobile, game-based or personal computing devices (e.g. desktop, laptop, tablet, game console and cell phone).

The possible options for the scope and composition of a STD portfolio are many and dependent on various training aspects, which may even change over time due to changing armed forces objectives and needs. There is never a single best option for such a portfolio as there are many choices to make among all these training aspects. These choices even interact with each other. Therefore, NLR's Simulation Training Device Portfolio Design Process and Control Panel method is applied (Figure 4). This method provides the major elements to consider in defining the outline for each new STD that should be incorporated in the portfolio.

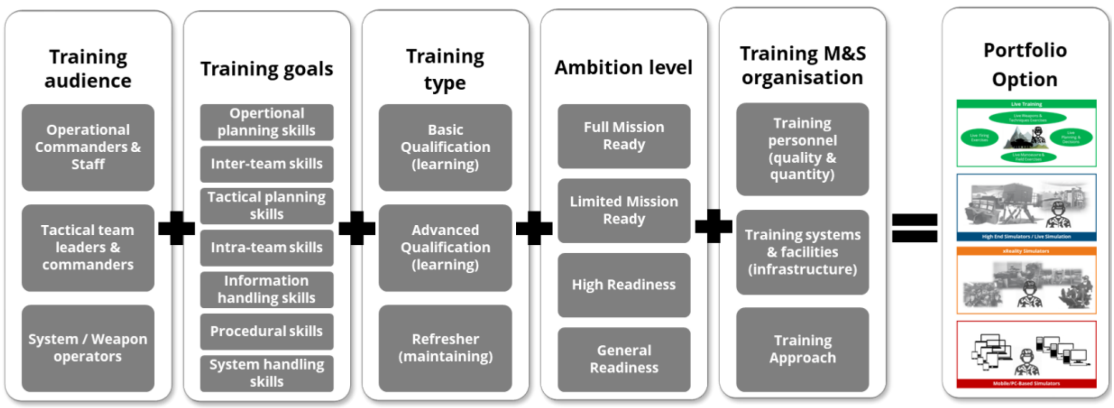
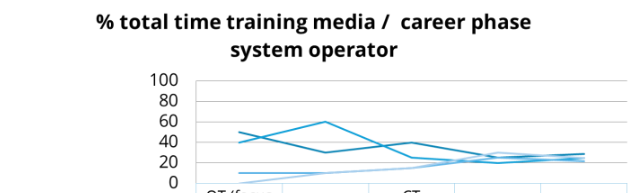


Figure 4 Simulation Training Device Portfolio Design Process and Control Panel

The basis of the process is the cost avoidance and optimization strategies of transferring live to virtual simulation training, and then specifying the optimal distribution of STD types and deployment in training time percentage, over the career path of each of the three global military function categories. This distribution applies the modern competency based training and blended learning approach of whole task training sequences for qualification (QT) and continuation training (CT). Here, one can see a shift in STD type needs over the military personnel career. The training time percentage distributions over STD are rough estimates (there is variation between the specific functions in a required training media balance over a career path), which are based on educated estimates by subject matter experts during a moderated workshop to establish consensus. In here first the media distributions (one for each of the four career phases) is estimated. Next the distribution over the full career is calculated as the weighted average over the training phases, based on the training time distribution estimates over the career phases of each military function category. A hypothetical example is depicted in Figure 5.



	QT (focus system handling)	QT (focus tactics)	CT beginning experts	CT experts	full career
Live	50	30	40	25	28.9
High-end sim / Live sim	40	60	25	20	24.6
xReality	10	10	15	25	21.5
Mobile/PC-based sim	0	10	15	30	24.8

Figure 5 Example – STD Training Time Distribution

Training Utility Enhancements Identification and Specification

Enhancement of the overall training utility, by means of increasing training effectiveness and efficiency in terms of outcomes, time and cost, can be realized by the implementation of common personalized training and artificial intelligence (AI) intensive training functionalities across all STDs in the designed portfolio. This effectuates the fourth element in the training and simulation capability optimization and cost avoidance strategy.

Personalized training builds upon a Performance Based Training concept in which computational learning and performance models are developed based on (performance) data, measured during training and operations. Such models can predict the most effective learning moment or the just-in-time refresher training. Initially, group models may predict performances for a specific group or unit. Later, more specific and (possibly) personal models can dynamically select the training moments, scenarios and the amount of training to the individuals' progress. Therefore personalised training requires a common advanced performance measurement, learning analytics and partly self-regulated learning system powered by AI functionality. Such AI functionality must be able to automatically select, sequence and tailor training scenarios, even in real-time, to fit exactly the needs of the trainee or his/hers progression through a training. This also requires more realistic constructive simulation entities (e.g. CGF/CFE), especially constructive and virtual team members who are not yet working on a functionally adequate level. Apart from emotional aspects, work-related (tactical) dialogues, behavior and facial expression are still in a very rudimentary level of maturity. In combination with smarter virtual instructors this will result in a reduction of human role players and instructors, with huge logistics benefits and availability of more rich, varied and scalable training scenarios that maximize the training outcome. To maximize their RoI these functionalities should be built on top of and making use of an armed forces' common simulation architecture, infrastructure, components & (Cloud) services capability (See Figure 6).

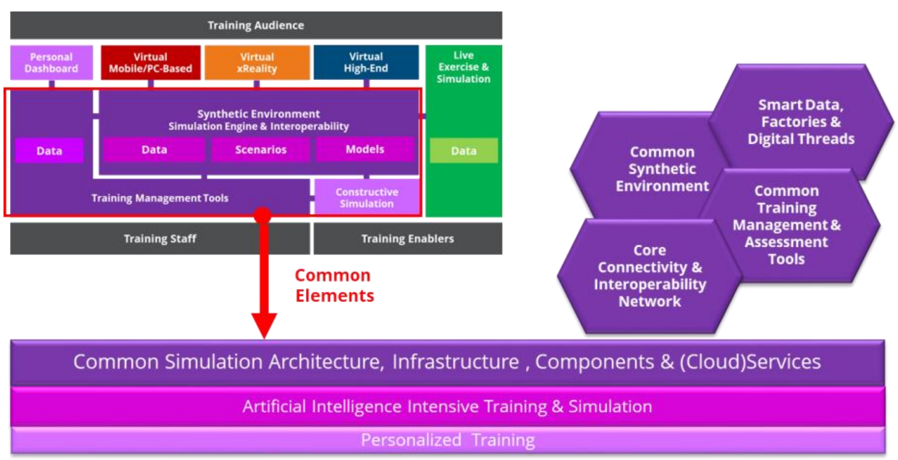


Figure 6 Joint Simulation Capability and Functional Components Reference Model

Common Simulation Architecture, Capabilities and Services Identification and Specification

The reference model as depicted in Figure 6 provides the basis to identify the common technical denominators that could possibly be separated out of an individual STD, and then standardized, shared and reused over each STD in the (re)designed portfolio. These common denominators are the technical means that aim at establishing synergy and coherence of all armed forces' STDs that are fielded throughout the country. This is realized by specifying and enforcing a common simulation architecture, standards and requirements onto each STD in the designed portfolio. This architecture should comprise a modular, common and open standards based design, with a clear decoupling of functional components and separation between on premise or mobile user interface and (cueing) simulator hardware from their underlying data, models and simulation engines, and training tools. The latter components could then be standardized and virtualized as central functions offered as shared resources and (cloud-based) services. Where these cloud-based services are hosted by multiple simulation center hubs and delivered through a dedicated and shared simulation network infrastructure such as the NATO M&S as Service (MSaaS) paradigm (*MSG-136 Task Group, 2018*). Furthermore, this network provides the core connectivity and interoperability network services, including standard cross domain security and gateways solutions to allow controlled access and secure capability interoperability with external (inter)national parties and live systems. These services ensure accessibility and interoperability of all fielded STDs in the portfolio needed for accomplishing modern net-centric, joint and combined operations training in highly scalable (inter)national collective mission training environments. Three other important common services are:

1. Common Synthetic Environment – A common shared synthetic environment facilitates reuse, acquisition and maintenance cost reductions, but also enables substantive interoperability in terms of a coherent and well correlated distributed synthetic mission environment (i.e. fair fight) for higher training outcomes.
2. Common Training Management and Assessment Tools – A common service that provides continuous management of training syllabi, content, scenarios, scheduling and after action review, whether it is individual, team, or collective supported by interoperable assessment tools and reusable data (e.g. xAPI).
3. Smart Data, Factories and Digital Threads – Smart data and digital thread services assure that all relevant data is gathered and stored digitally, linked, accessible and analyzed anytime and anywhere it is needed in the whole training and simulation capability. They are the key enabler for modern data-driven personalized training and business management, which provides transparency and controllability of training outcomes and cost based on true data. Smart factory services leverage both these services for (partly) automated data-driven training exercise development. They provide the agility and speed that are essential for developing or updating training scenarios, common synthetic environment and other simulation models to keep the capability in sync with the fast changing real operational environment and needs.

A joint simulation capability capable of an organization wide delivery and re-use of shared training and simulation services, tools, scenarios, models and data eliminates redundancy, reduces complexity and establishes synergy, and hence optimizes the overall portfolio return on investment. Furthermore, it increases the sustainability and substantive interoperability of the armed forces' portfolio as a whole, but also facilitates easy local adaptation (e.g. updates and upgrades) of individual STDs to today's fast-changing COTS immersive and digital technologies and innovations.

ANALYSE CAPABILITY OPTIONS

The valuation analysis comprises the assessment of the impact of each of the designed training and simulation capability options on the following three key areas: training value, technical quality, and total cost of ownership. This assessment is conducted both on individual STD and overall armed forces' capability level (See Figure 7). It is beyond the objective and scope of the present methodology to conduct an in depth, detailed and rigorous valuation analysis. Even if a more detailed analysis would be required, this would not be feasible given the current lack, access or availability of the required information and data from both public sources and armed forces internal sources. At present, many armed forces do not have such necessary information and data readily available. Therefore, the analysis approach aims to provide a first rather course-grained insight by estimating raw order of magnitude and main trends of the various designed options on the key valuation areas in comparison to an existing armed forces training and simulation capability. This means that the valuation analysis comprises rather a relative assessment than a one in absolute sense or figures. Quantitative best-estimates are given where possible or otherwise qualitative, along with risk factors for these valuation results, the actual implementation and the organizational impact of each option.

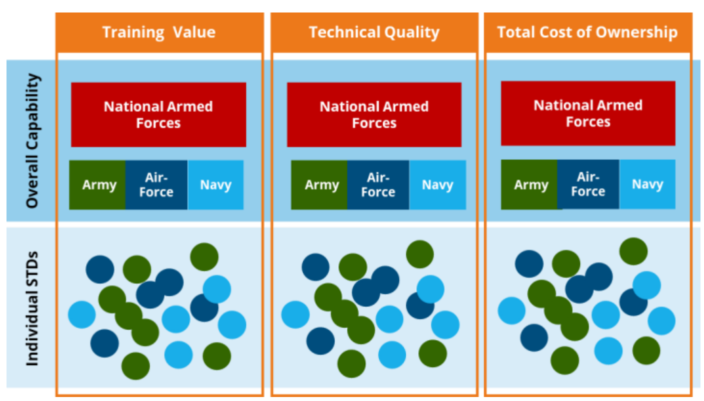


Figure 7 Training & Simulation Capability Valuation Framework

Training Value and Technical Quality Analysis

To analyze the training value of each training and capability design option, a small set of most relevant assessment criteria is applied:

1. Future mission training coverage: the ability of the training and simulation capability option to cover all training goals for the future missions expressed on a percentage scale, where 100% means full coverage;
2. Personnel readiness level: the readiness level that could be attained from training with the capability option on a percentage scale, where 100% means full mission ready;
3. Total training time to proficiency: the percentage increase or decrease of the total training time needed to reach the readiness level from training with the designed capability option relative to the current capability.

These training value criteria have been identified from the set of actual optimization strategies and boundary conditions from various training system (re)design and training simulation facilities modernization projects we have supported. All three training value criteria are scored for each of the three global military function categories per designed training and simulation capability option. This scoring is currently done by means of guided training subject matter experts workshops with both armed forces internal and external experts. Therefore, the resulting scores are averaged educated estimates, which should be compared primarily in a qualitative and rather relative way. The training value criteria scores have considerable uncertainty. Until real evidence is available, these estimates are the prime training value data for comparative analysis and strategic decision making between the different options. The results are visualized in bar diagrams for each option and the three global military function categories to enable an easy comparative analysis.

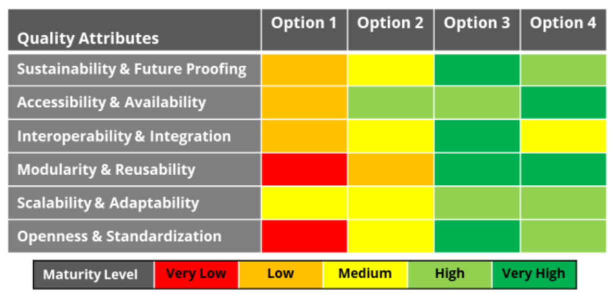


Figure 8 Technical Quality Heath Chart - Example

The technical quality analysis objective is to assess the technological maturity of the underlying simulation training device and the overall joint simulation capability hardware, software, infrastructure, models and data for each designed training and simulation capability option. This maturity is described in terms of the set of six technical quality attributes as listed in Figure 8 and are scored in the form of a five-level heath chart. This scoring is conducted in a similar fashion as is done for the training value criteria but with simulation experts instead, since often hard information for this is limited from the armed forces themselves and from industry. In general the higher the maturity level the more efficiently the core function of the training and simulation capability is: the provision of a highly scalable and adaptable training environment in scope, complexity, content and realism, and an environment that is available anywhere and anytime, easy to use with low training utilization overhead. Moreover, high levels imply a highly sustainable capability and ability to respond properly, rapidly and with lesser expenses to technological changes and innovations over time.

Total Cost of Ownership Analysis

Publically available sources on structured return on investment analysis of training and simulation capabilities are scares. Recent NATO SAS RTG efforts show that despite several decades of R&D effort such methods are still very premature, and scientific information and data for such analysis are unavailable or at best incomplete, inconsistent, inaccurate or even obsolete (*SAS-028 Task Group, 2003, SAS-095 Task Group, 2016*). Furthermore, from our experiences the armed forces themselves do not have the complete detailed overview of actual and historical figures needed for a rigorous quantitative analysis. Therefore, total cost of ownership for each designed option is analyzed relatively to the current situation, referred in the methodology as option 0, and not in an absolute sense. The designed method for this purpose applies a cost avoidance and investment estimation, which integrates the best possible publically available cost and investment information for modern training and simulation capabilities as a referential basis (*Van Ryswyck 2018, Cooley 2015, SAS-095 Task Group, 2016*). Next the current armed forces situation and future options' costs and investments are estimated by means of scaling, interpolation and extrapolation of this referential basis for the specific armed forces context and the data actually available to them. Confidence intervals are used to express the level of uncertainty in these estimates.

Table 1 Relative Incurred STD Costs

STD Categories	Operational and sustainment cost (% relative to live sim / field training)
Live sim /field training	100
High-end	15-25
xRealtity	10-15
Mobile / PC-based	5-10

The total cost avoidance estimate method comprises three steps. The first step and basis for the estimation method is the cost-avoidance framework of Cooley et al. (2015). The overall principle of cost avoidance is: Net costs avoided are costs saved by not performing training live minus costs to operate and maintain simulation-based training (i.e. Strategy 1). Here, no initial investments or procurement costs are taken into account; these will be estimated separately in our method. Only the annual operating and sustainment costs of STDs are compared to the operational, primarily variable costs (e.g. ammunition, petroleum, oil, lubricants, corrective maintenance, vehicle usage, and track pads and tires wear) of the real live training systems. When such data are available, e.g. cost figures for comparable live training systems as used in the *Van Ryswyck (2018)* study, it is possible to extrapolate the cost savings by this partial transfer to a full transfer from live simulation or field training to virtual simulation training only. To adapt this potential maximum cost savings to any another armed forces situation, a weighted ratio between these data, e.g. as found in the *Van Ryswyck (2018)* study, and the other armed forces' live training systems is estimated by a cross comparison of real systems types, features and numbers. When transferring to virtual simulator training, additional costs for this type of training are incurred. The operational and maintenance costs for training simulators are estimated relative to the operational and sustainment costs for live simulation training. Table 1 lists the subject matter expert's estimate of the relative operational and sustainment incurred cost for the three other training simulation device categories with an upper and lower band confidence interval, as based on our experiences and other external expert opinions. With the estimated figures for cost savings and additional cost incurred, cost-avoidance estimations are derived for each of the designed capability options and their associated STD category training time distribution (e.g. Figure 5) over the career path of each of the three global military function categories. The cost avoidance is then calculated as follows:

Total Cost Avoidance = *Cost saved – additional cost high end – additional cost xReality – additional cost PC* (2)

Where:

Cost saved *= (Current share live training – future share live training) ×*
(maximum potential cost savings by full transfer to virtual simulation training) (3)

Additional cost high end *= (Future share high-end training – current share high-end training) ×*
(operational and sustainment cost by full high-end training)

Additional cost xReality *= (Future share xReality training – current share xReality training) ×*
(operational and sustainment cost by full mix training) (4)

Additional cost PC *= (Future share PC training – current share PC training) ×*
(operational and sustainment by full PC training) (5)

This total cost avoidance is subsequently corrected for the share per military function category in the total training:

Cost Avoidance per military function **=** *(share of the Army function)* **×** ***Total Cost Avoidance*** (6)

Where the shares of each military function category is: **100% =** *System operator* **+** *Tactical team leaders & commanders* **+** *Operational commanders & staff*. These shares in the total training costs are estimated based on an average composition and size of armed force units.

The second step of the total cost of ownership estimation method comprises a correction due to the application of common simulation architecture, capabilities and services. Currently, there are no hard figures available on the exact amount of investment needed and cost savings gained from implementing such simulation capability coherence options. However, normal business IT domain experience learns that the implementation of common architecture, shared data, model and cloud-based services results in yearly average IT cost saving of about 20%. Since simulation technology can be considered as a specialization of common IT, it can be expected with reasonable certainty that the minimal cost reduction for simulation capability options will lay somewhere in the range of 10% - 30%, depending on the maturity levels of the quality attributes (Figure 8). The actual percentage cost savings is estimated and calculated as corrections to the future share of high-end, xReality and PC-based STD categories in equations (3)-(5).

The third step of the total cost of ownership estimation method comprises a correction due to the application of common personalized and AI intensive training (Figure 6) to enhance the overall capability's training utility. Because armed forces world-wide are in the process of transferring to personalized training and AI-intensive training, no actual information on these savings exists. Currently, we assume that the total cost avoidance, as calculated by equation (2), will in total increase with at least 4% - 6% due to a reduction of logistic, human training resources (e.g. instructors and role-players), and optimal trainee sequencing over the available STDs.

The method to estimate the initial investment to implement a capability option uses a similar calculation approach as in step 1 of the total cost avoidance calculation. In this method however the best known initial investments of the current armed forces training and simulation capability (i.e. option 0), either known or estimated or combination of both, are used as the referential basis. Moreover, the assumption is that the current simulation capability primarily comprises high-end simulation training devices, and that the investment costs for xReality and PC-based STD are in the range of 20-30% and 10-15%, respectively, of the cost of a high-end STD. Our first educated and provisionary estimate for the investments needed to implement common simulation infrastructure and services, personalized and AI intensive training functionality is in the range of 15 - 25% of the total investment needed for the newly designed STD portfolio, depending on the maturity levels (Figure 8) and the armed forces own ambitions in this regard.

Based on the outcomes of both the total cost avoidance and relative initial investment estimates a total net cost savings for each option can be calculated by selecting an expected life-cycle of the new training simulation capability. These total net cost savings estimates provide an initial indication of the return on investment for each designed training and simulation capability option, which can support armed forces stakeholders in their strategic decision process on the best capability option to pursue the future. Figure 9 provides a fictive example of the possible outcome of the total cost of ownership analysis for a 25 years life-cycle and its graphical presentation.

Total Net Cost-Benefits in M€ (rounded)	Total Cost Avoidance (yearly)		Total Cost Relative Investment (initial)		Total Net Cost Savings (25 year life-cycle)	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Option1	95	115	1100	1775	630	1775
Option 2	115	130	560	965	1910	2690
Option 3	105	120	130	245	2380	3130

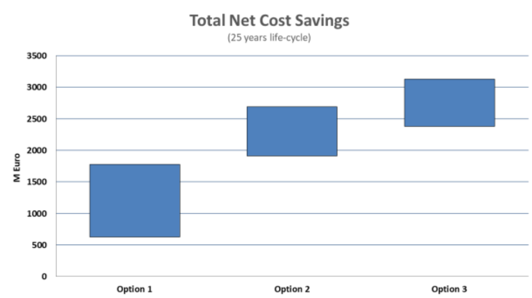


Figure 9 Example – Total Cost of Ownership Analysis Outcomes and Presentation

SELECT AND IMPLEMENT A CAPABILITY OPTION

Once the C-TNA has been performed, the training and simulation vision has been constructed, and the options for the training and simulation capability have been identified, designed and analyzed with respect to the training value quality and cost, the armed forces higher command has to decide on what would be the best value capability option for their situation. Since each capability option has been outlined as a broad training landscape, its implementation requires considerable effort and time. For that, an implementation roadmap is required. Also, many factors in the rationalization and valuation process have been based on a considerable number of assumptions. Therefore, the roadmap should include measures to refine the analysis and reduce uncertainties using more detailed and objective data. The roadmap may include the following steps, which overlap in time:

1. Reinvent the processes of procurement and training management throughout the organization. Ensure that decisions and budgets relate to a full life cycle perspective with respect to both human resources as well as material. This is prerequisite for achieving that the overall training costs for specific military operational functions are minimized given an optimized training value.
2. Establish a persistent and data-driven training (e)valuation framework:

   a. Identify data to collect for training value and training costs purposes;
   b. Consolidate training value, costs and technical quality information;
   c. Continuously analyze, decide, and improve based on evolving insight.
3. Implement the training and simulation capability gradually in an evolutionary manner.
4. Perform function specific TNA's to specify specific training types and simulator requirements within the framework of the selected simulator portfolio option.
5. Upgrade or replace training facilities gradually.
6. Implement training utility enhancements gradually.
7. Refine/adjust the training & simulation vision and capability options following regular trend watches, actual consolidated progress and lessons-learned.

Technically, not all envisioned features are functioning or operational to its full potential currently. The joint simulation capability requires further development and standardization. Also, the promising features of personalized training and AI intensive training still require a long period of maturing before a fully operational implementation with optimal benefits can be expected. Although fully data-driven personalization will not be achievable in the short run, it will be necessary to start collecting performance data in much more detail than today and implement performance based training principles as a stepping stone towards personalization. Moreover, AI-enabled training functionalities can already be applied immediately in rudimentary ways. It is particularly relevant to start building the technical and organizational infrastructure for this today which will ease later implementation: measurement of data, modelling tactical (team) and other human behavior, and if desired, preparing personnel towards self-responsible and personalized training.

CONCLUSIONS AND FUTURE WORK

In a range of projects we supported a variety of defense organizations in making strategic decisions on their training system and optimizing their methods or simulation capabilities. Furthermore, we supported specific procurement of simulation training devices and assessed their technical quality and validity for training. We also learned from working together with other nations in NATO task groups. The major observation is that many armed forces still have a hard time in taking well-informed and strategic decisions with respect to training and simulation based on true insight. The information and data available are often limited, fragmented, subjective, obsolete, and difficult to combine and analyze. Further, decisions on the training system are made from a local (i.e., one phase in one training pipeline) and often one dimensional perspective, such as reducing costs for initial qualification. We advocate a comprehensive approach that is data driven and evolutionary and that takes the full career cycle as the basis for making cost driven decisions, given a clear standard for minimum proficiencies. Maximizing overall training and simulation return on investment requires a restructured organization of training, and procurement and sustainment of STDs, where goals and processes relate to global instead of local demands. This requires recognizing that minimizing costs for the full training pipeline may require accepting a high price for a certain component. When the ability of monitoring training value, quality and costs in high detail and objectively becomes fully operational, armed forces should be able to take true rational and faster strategic decisions on training and simulation capabilities within a decade. Although the role of technology is facilitating, it is essential. Without progress in common simulation architecture, services as wells as related digital technologies, artificial intelligence and data science, it will be hard (or perhaps even impossible) to maintain high readiness levels while accommodating vastly changing operational and training needs. The good news is that these technological areas are truly progressing rapidly.

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