A System of Systems Approach to Warfighter Training

David Parkinson
BAE Systems
david.parkinson@baesystems.com

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Abstract

This paper explores the traditional Systems Approach to Training (SAT) for the Warfighter, suggesting improvements for complex large-scale, live, and virtual training systems. Such systems are required to deliver military effectiveness and enable Readiness & Sustainment (R&S). It has long been accepted that the proper way to design training is by adopting a systematic approach to assessing the training gap, the design of the syllabus, and the evaluation of the performance improvement. This Systems Approach to Training (SAT) parallels Instructional Systems Design methodology, the latter also being a model to aid in the design, development, and delivery of a training program. The paper discusses the complexity of such large-scale military training systems and presents a case for designing them using Systems Engineering (SE) principles. The traditional SAT method applies, but does not cope with the overall requirements capture, architecture design or interoperability; nor was it designed to do so. Complex large-scale training systems are human centric and consequently should be designed using the most appropriate Systems Engineering (SE) processes, methods and toolsets.

Introduction

It was quite easy 100 years ago to design a training system (Fig.1). In fact design is probably not a valid terminology; training was achieved through necessity and experience. In the air domain, as manned flight started to evolve, training platforms were composed of easy-to-master basic controls. Complexity of training systems increased exponentially within the last 40 years with the advent of software systems. Human factors integration became a science and the psychologists discovered an opportunity to derive training needs from Warfighter performance. And so began the virtuous circle of continuous improvement of training through technology, innovation and underlying process.

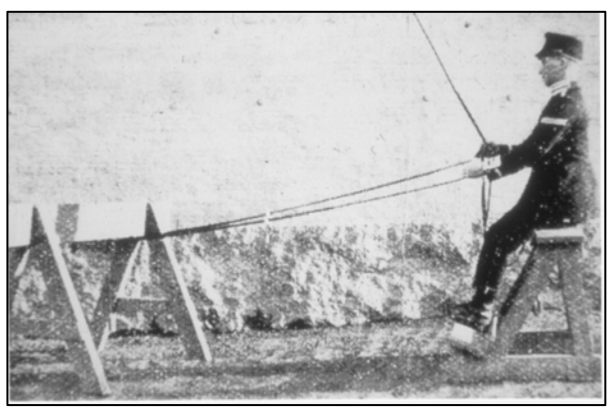

Figure 1 Early Simulator

The battle-space of today is depicted by the ubiquitous Network Centric Warfare (NCW) image (Fig. 2). If our armed forces are going to "Train as You Fight" (Klose, Mayk. 2004) then the training system arguably will have to be at least as complex, and possibly even more so, and employing a range of Live, Virtual and Constructive (LVC) training assets. The training system will include many real platforms, some with augmented or embedded training. Given that such assets are expensive to

Figure 2 Networked Centric Warfare Example.

deploy, virtual training systems will be used much more as part of the collective training scenarios as well as for normal individual or team training purposes. Large scale live training exercises will steadily reduce the dependency on live assets and introduce more virtual systems and synthetic environments. Such complex systems do need designing.

This paper discusses the complexity of such large scale training systems and presents a case for designing them using appropriate Systems Engineering (SE) principles. The traditional Systems Approach to Training (SAT) does apply, but does not cope with the overall requirements capture, architecture design or interoperability; nor was it designed to do so. The normal SE approach applies, but this too can be weak in the capture of operational requirements, human needs analysis and in-service evaluation. It therefore suggests that such training systems should be designed using an integration of both SE and SAT, and more importantly adopt the emerging SE awareness and understanding for designing complex Systems of Systems (SoS).

System Complexity

First of all let us explore system complexity. Generally speaking complex, evolving systems are systems that are very distributed, are not designed to an original specification, but instead begin to include incoherent stakeholders who have created systems that are functional for other purposes. They are then brought together to form a complex system because the individual "agents" of the system see such cooperation as being beneficial. In the real Battle-space the uncertainty introduced by the instantaneous interaction between interacting platforms makes it almost impossible to predict the behaviour of the complex systems of systems. Some of the systems (enemy) are actively seeking to disrupt the achievement of system of systems goals. The absence of essential co-operating systems (friendly) may also disrupt the achievement of system of systems goals. The scope of the operating environment to prevent the expected interactions is also a source of uncertainty.

A large scale training system should, by definition, have many of the above complexity attributes. This can be illustrated in Table 1, against a sub-set of system complexity attributes (Kuras, White 2005).

Table 1 Complexity of a Training System

System Complexity Attribute (Source Kuras & White)	Training Context
Unique	Joint exercises configured for 1-off purposes with selection of available assets and participants. Student behaviour; Interaction between live and virtual players; Interoperability and “fair fight”; Mission specific; Training plan;
Development and operation concurrent and continuous	Training evaluation; Operational tactics; Training Requirement; Emerging threats; Concurrency with platform; Mission rehearsal role.
Emergence: development and operation at multiple scales	Individual, team and collective training; Planning and scheduling large networked simulated exercises; Number of training nodes; Impact of network failure; Geographic area of interest; Coalition training; Training centres; Deployed training; Distributed learning.
Stochastic, unpredictable	Political influence; Weather; Availability of resources; Change of Doctrine; Reliability of assets.
Learning and memory of prior history alters behaviour	Fundamental to any training regime; Operational feedback; Training evaluation;
Requires both co-operation and competition to function	Individuals, teams and friendly forces need to cooperate; Competion for resources; Pride; Standards; Training Governance; Government agencies, Industry, Planners, White Forces; Instructors; Maintainers; Budget holders

There are far more subtle levels of complexity in a training system. These stem from the learning style, the psychology of learning, skill retention and cultural differences, which are apparent in coalition training exercises. Measuring training effectiveness is still difficult, adding complexity when trying to optimise the solution. Also, the very fact that training is still treated as an after thought in far too many instances adds to this complexity. It might be said that the lack of training focus during the conceptual phases of a new (real) system is the root cause of some of this complexity.

The Human Dimension

The human dimension theme of the conference has particular significance in the design of Training Systems. It is “a bridge between human-related data and design” (MIL-HDBK-46855A). (Fig.3) Human Factors Integration (HFI) not only enables systems to be usable and more effective, it also considers the need for training at an early phase of the system life-cycle. Typical activities are a contribution to the user requirement, human computer interfacing, evaluation and assessing operational performance. In the UK, the Ministry of Defence Architectural Framework (MoDAF) now has a complementary Human View (Bruseberg 2008). The harmonisation of HFI and Architectural Frameworks is an obvious improvement, which allows the HF community to communicate more effectively with System Engineers. The HF dimension introduces Performance, Change and the interaction of people and technology aspects of SE which are too often lacking. (Fig 3) (Bruseberg 2008)

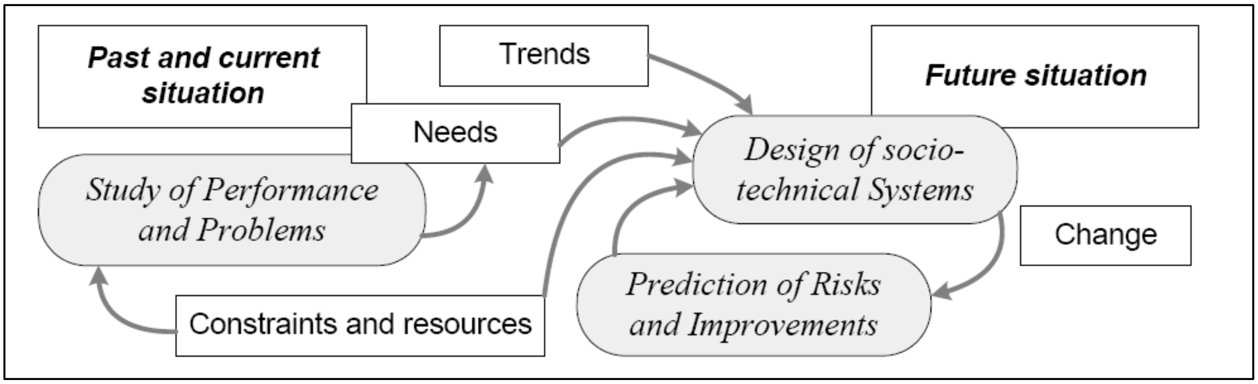

Figure 3 Human Factors Bridge

All these have direct relevance to the design of a training system and there should therefore be close co-ordination throughout the whole life-cycle. Unfortunately this is not always the case due to contracting routes, size of project teams or poor project management. This becomes more of an issue as the size and complexity of the training system increases, where the technological factors such as simulators, networks and synthetic environments can dominate the design parameters and planning.

Whilst the importance of designing a platform for optimum human performance is not new and has been subject to much research and a plethora of guidelines (e.g. MANPRINT), there is still a need to establish a closer relationship with the live, virtual and constructive training systems. From a live perspective, this is improving as embedded, or augmented training, is incorporated into platforms (Parkinson. 2006), bringing training design into the heart (and mind) of platform design. This goes beyond the traditional human factors in terms of designing the platform for ease of use and effective operational performance, it addresses one of the main purposes of the platform; training. Based on the premise that if you are not fighting wars then you are training, the training needs should be a key requirement, and not delegated solely to a separate training system comprising synthetic training aids and classrooms. The need to improve the training effectiveness and the availability of technology, predominately real time embedded computing and computer graphics, has led to much more focus on designing training into the platform. This results in enhancing the training exercise through augmenting the real world with synthetically generated entities. The ability to network live and virtual training systems has encouraged people to look at the overall architecture and design of such systems concurrently with the operational requirement. It is the human dimension which maintains the focus on user (training) requirements and should be rigorous in its application at all times, not just during the training needs analysis. Recent research in the UK has made a strong connection with HFI, Systems Engineering and Enterprise Architecture, in this case the training enterprise (Bruseberg et al. 2008). This paper points out that HFI often informs the design, whilst SE takes the role of managing the design.

A Training System of Systems

We can explore the SoS Engineering nature of a training system using the characteristics taken from the SoSE Centre of Excellence. This summary is shown in Table 2.

Table 2 SoS Characteristics of a Training System

SoS Engineering Characteristic		Training System
Purpose	Developed to provide broad capability and enable interoperability	Requirements include emergency procedures, tactical scenarios and mission rehearsal.
Architecture	Dynamically reconfigured as needs change	System needs to be reconfigurable depending on the training exercise. Transient availability of assets. Includes Live, Virtual and Constructive training systems
Interoperability	Standards permit independent operation and SoS interoperability	The training industry has developed many standards used for interoperability
Optimisation	Optimised for both individual system and SoS performance	Training systems are required to be optimised for individual training and large scale collective and coalition training exercises
Behaviours	Flexibility and adaptability to accept legacy, emerging, and ad-hoc systems behaviours	The requirements for training systems now invariably include agility, flexibility and modularity in order to adapt to changing operational needs, emerging technology and student throughput
Acquisition & Management	Separate acquisitions managed independently	Very much so, unfortunately! The platform, and platform modification, is often procured without early consideration of the training system. Large scale exercises interconnect legacy systems and systems from different Original Equipment Manufacturers.

Whilst a training system might not equate to the classical System of Systems (Kaplan. 2006) it does show a close matching of characteristics. Furthermore the definition of a System of Systems Engineering (Kaplan. 2006) also relates closely to a training system.

System-of-systems engineering is the cross-system and cross-community process that ensures the development and evolution of mission-oriented capabilities to meet multiple stakeholders' evolving needs across periods of time that exceed the lifetimes of individual systems.

This paper shows that this accurately describes the type of training system which is needed today to deliver military effect.

(Quadrennial Defense Review Report 2006)

"Although the Military Departments have established operationally proven processes and standards, it is clear that further advances in joint training and education are urgently needed to prepare for complex, multinational and interagency operations in the future.

A Typical (Complex) Training System

Figure 4 Typical Training System of Systems

A typical complex training system is depicted in Figure 4. This becomes more complex and aligned to the above SoS characteristics when live training, collective training (Land, Air, and Sea) and coalition forces are linked over a Wide Area Network (WAN). Such systems have evolved over recent years in response to military requirements (budgetary and operational) and have been enabled by new technologies.

This of course is still only a part of the system. It does not include the pre-operational training in terms of basic military training, continuous personal training or platform conversion / familiarisation training. It does not include the other training pipelines needed for the maintenance of the operational equipment and overall supply chain. These are also Systems of Systems which should be viewed in a very similar way.

System Engineering

Introduction

Given training systems are complex SoS it follows that their design should adopt the appropriate SoS design methods and tools. Much of the literature on SoS and system complexity, and development of methodology, is aimed at Network Centric Warfare (NCW) or Network Enabled Capability (NEC). Indeed, it is rare to find much treatment of SoS outside of these domains. If we have to design training systems to create as "real" an environment as necessary to train, employing much of the complex real world, augmented by the synthetic environment plus simulated tactical scenarios, then it follows that the same methods and toolsets need to be employed to design the real SoS. This seems obvious but nevertheless it is not normal practice. High fidelity simulators and some part task trainers are designed using Systems Engineering. But lower fidelity training systems, or devices, tend not to be, especially when using a large degree of commercial off the shelf technology. Conversely large-scale networked synthetic training systems might be "designed" in terms of a network, maybe even in terms of architecture, but not usually in terms of a training system

A Systems Approach to Training

Before returning to SoS Engineering let us explore the traditional systems engineering approach in the training domain. The SAT process (Fig. 7), or Instructional Systems Development (ISD)

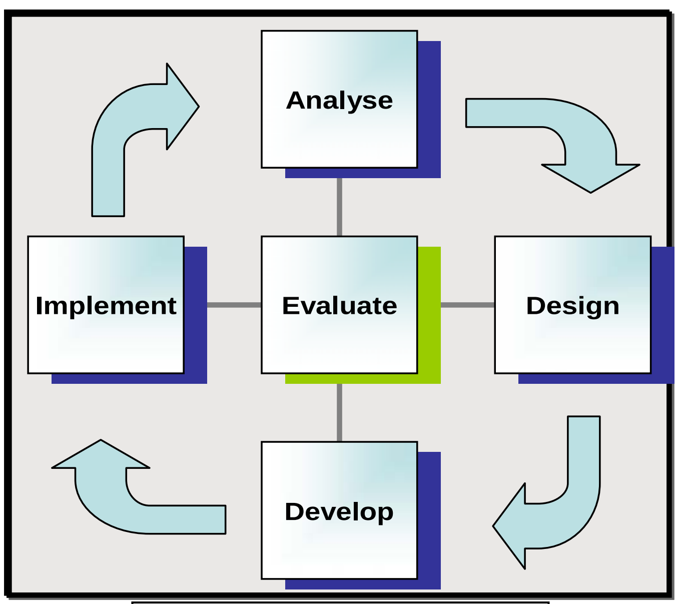

Figure 7 A Systems Approach to Training

process, is an application of systems engineering to the training system. It is worth pointing out though that there is greater emphasis on evaluation. (System Engineers take note!). The process is very much based on knowledge, skills and overall system performance. It is, by definition, human performance centric.

The Analysis phase is analogous to requirements capture, including the identification of stakeholders. The Analysis phase also usually builds performance measures for the tasks to be trained. The Design & Development phases are quite standard activities, including extensive verification and validation of the instructional courseware. The Implementation normally comprises the creating of a management plan and the delivery of the training. The early stages of delivery can include a substantial amount of acceptance and qualification, which can cause conflict with the normal SE final phases covering other parts (i.e. training aids; simulators; facilities) of the training system and lead to difficulties in demonstrating that the customer requirement has been met. The Training Needs Analysis (TNA) is usually underpinned by a database management system given the vast number of requirements (e.g. learning objectives) which need to be managed (e.g. decomposition, traceability, configuration control). Unlike SE, there is no universally accepted standard database management system (i.e. DOORS, CORE, Cradle), which is a weakness resulting in poor through life management and sharing of best practice.

Evaluation includes the review of each phase and the through life, in service continuous improvement of the training effectiveness. This can include external evaluations (even audits) to ensure that the training standards are being maintained. This is a major factor in satisfying corporate governance, safety and duty of care mandates. In summary, the five phases are activities that continue throughout the life of the training. After building a training system, the other phases do not end once the training is implemented. The five phases are continually repeated to see if further improvements can be made. (ISD Handbook)

Architectural Framework

Returning to the more complex training system, architecture planning is critical to SoS development and the way we treat architecture requirements and design is fundamental (Biddle. 2006). There are many Architecture Frameworks (AF) which have been developed to satisfy differing needs (e.g. Zachman; TOGAF; DODAF; MODAF). Even so, there is still much ongoing research into "Architecting", and in particular relating it to capturing the customers' needs, or indeed what he thinks he wants, and the envisaged solution (Touchin and Dickerson. 2008). For most levels of system complexity, it is not appropriate to use "PowerPoint" as the preferred toolset (!), but all too often this is the only means used to communicate the intended SoS.

Given the depth of complexity of a SoS and the need to plan the whole capability life cycle, the relevance of AF is becoming more evident. Whilst training is complex in its own right, it is still only one of the capabilities the military customer considers. BAE Systems is examining the requirements of Through Life Capability Management (TLCM) and in particular the contribution of SE. In the UK TLCM tends to mean the "harmonisation" of the other MoD seven lines of development (Equipment, Personnel, Information, Doctrine & Concepts, Organisation, Infrastructure, Logistics), so the analysis and design of the training system needs to be done not in isolation of these, but within an integrated and interoperable framework. Immediately SE has to cope with the complexity of stakeholders and requirements, plus the whole life cycle rather than the initial in service acquisition, or manufacture phase. Traditionally industry has concentrated on equipment, some logistics and a small amount of training. This is no longer a viable business model for TLCM or through life availability. The most common Architectural Frameworks used in the defence industry are the US Department of Defense DODAF, and the one derived from DODAF promoted by UK Ministry of Defence MODAF (I will use MODAF as the basis of this section). Given the close association of the real world and the live and virtual world of a training system, it is relatively easy to show the benefits of MODAF when designing a complex training system. One of the strengths of an AF, and certainly MODAF, is the many different views which can be derived from a common source of data, each viewpoint aiming to help specific stakeholders, or decision makers. MODAF consists of six viewpoints which cover all of the main perspectives and dimension that are required in order to conduct the core MOD processes around acquisition, sustainment and operations. It is easy to see how the training system can benefit from such a framework during the concept phase and capturing the requirements. (Table 3)

Yeoh, Syn, et al show the importance of using an AF to underpin the lifecycle and overcoming the "stovepipes" of a traditional SE approach. The AF can "institutionalise" such a process of disciplined analysis and governance for enterprise system development. (Yeoh, Syn, et al. 2007).

The delivery of training is often through a contracted service, either in the form of a bespoke training facility or as an integral part of the platform prime contract. Either way, it is increasingly important to consider the training enterprise architecture in terms of the business requirements, information management and change management, whilst maintaining a strong relationship with the traditional systems engineering.

Table 3 Training System Architectural Viewpoints

Viewpoint	Description	A Training System Perspective
Systems Viewpoint	Documents system functionality and interconnectivity to support system analysis and through-life management.	Describes the main live, virtual and constructive training systems, the networking, training management system, briefing / debriefing, synthetic environments, relationship with platforms, syllabus management.
Acquisition Viewpoint	Documents acquisition programme dependencies, timelines and all lines of development status to inform programme management.	Training is one of the prime development needs in the deployment of new military capability. In the UK the capability model is based on Equipment, Personnel, Information, Doctrine & Concepts, Organisation, Infrastructure & Logistics.
All Views	Provides summary information for the architecture that enables it to be indexed, searched and queried.	Provides an overview of the training system and associated data dictionary.
Strategic Viewpoint	Documents the strategic picture of how military capability is evolving in order to support capability management and equipment planning.	Training has often not been included in this viewpoint. Consequently equipment has been developed without any consideration of the training need.
Technical Viewpoint	Documents policy, standards, guidance and constraints to specify and assure quality expectations.	In the Simulation and Training industry, much of the policy and standards have been aimed at integration and interoperability. e.g. High Level Architecture (HLA); Joint Semi-Automated Forces (JSAF); Test and Training Enabling Architecture (TENA) and various defence training standards
Operational Viewpoint	Documents the operational processes, relationships and context to support operational analyses and requirements development	Describes the contexts or scenarios in which the training system is to be used. Identifies participants, information exchanges, operational activities, organisational relationships and event traces. May be used to represent the overall system and the environment in which it operates, or specific scenarios and operations such as close air support (CAS) or Suppression of Enemy Air Defense (SEAD) Operation.
Source MOD Architecture Framework		

The design of a training system not only has to demonstrate that it is delivering the training goals, it has also to continuously measure the training effectiveness, feeding back results into the overall SoS design. This is another reason why the underpinning AF must manage the whole lifecycle and be able to perform during the long delivery phase. There are a number of methods and toolsets which can be used for the design of the delivery system. Processing mapping, system simulation and many techniques derived from the design of a Service Oriented Architecture (SOA) are all applicable. Halley (2005) makes the connection between SE and SOA in general terms, which are very pertinent to the delivery of training. Takeda and Kenny (2008) also describe the relationship between the training and simulation standards (e.g. High Level Architecture), SOA, Web Services and Software and Cloud Computing. The focus on SOA, coupled with the issues of a complex SOS shifts the requirements to one of capability and service provision, or at least adds these to the requirements database. As training need usually results in a training service provision, not a product, some blend of AFs is needed for the complete SoS design.

Harmonisation of SAT and Systems Engineering

SAT and SE are based on similar methodologies, starting with requirements capture, transitioning

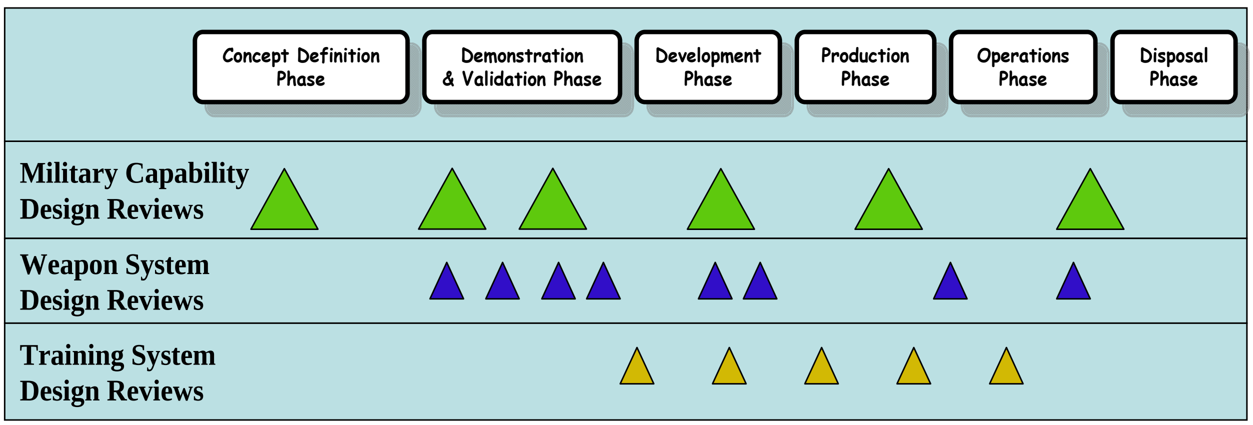

Figure 9 Representative Lifecycle Phases

through design maturity and into operational use. A representative lifecycle, illustrating the phasing is shown in Fig 9. However, representing this as a linear series of phases, with design reviews at appropriate, sometimes arbitrary milestones is not a true reflection of reality. SE is more of a spiral, or a series of concurrent, incremental developments. The development of the training syllabus and courseware follow a similar path, but lags behind the main weapon system platform, or capability design until the design data is stable. The phasing of the weapon system, the training system and training courseware in terms of lifecycle management is often a source of problems so needs careful project management. Trying to integrate this into the SE of through life capability, where other weapon systems, logistics and infrastructure have to be taken into consideration only compounds the issue. Also, the typical “in service support” phase of a lifecycle is often a gross misrepresentation of the importance of SE needed to support system upgrades, urgent operational requirements and the training evaluation part of SAT which occurs, during this majority time span of the lifecycle.

More often than not the SAT project is not closely aligned with the weapon system SE, giving rise to failures in the configuration management of training content, extensive rework and a breakdown of the (implicit) coherent AF viewpoints. Duke (2006) proposes a Top Down Functional Analysis (TDFA) as a methodology for the systems engineering approach that is used to determine and manage the integration of human performance requirements with the system design process It is a very good illustration of how SE and SAT co-exist. In the diagram (Fig 10)

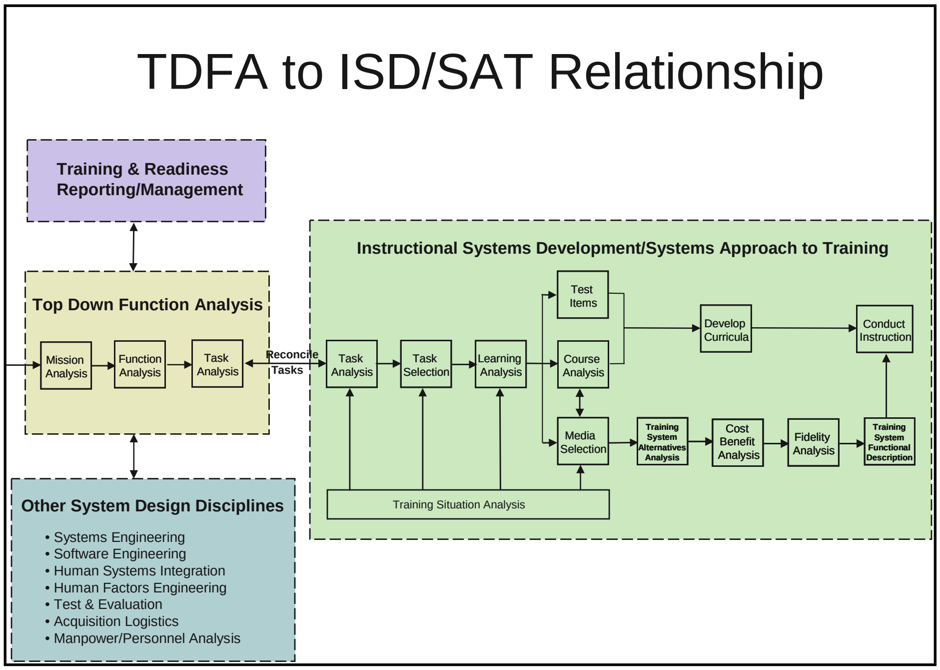

Figure 10 The TDFA Relationship to the Instructional Systems Development (ISD)/Systems Approach to Training (SAT) Process

(Duke 2006) the emphasis on the training lifecycle is clear to see, with the "other" SE appended to the functional analysis. This is typical of how a training system is designed for a particular platform. A SoSE approach would provide much more integration, in particular the traceability of operational requirements, assessing the training media options, including live training and resulting in a more timely delivery of the military capability. In other words, the design of the SE framework should embrace the breadth of military capability requirements, the depth of the systems of systems and the continuum of improvement. Arguably, the design of such a system, or framework, is more important than the training products and services to be utilised. Even this system needs to be continually improved as a result of lessons learnt, maturity management, management of key performance indicators and training effectiveness.

Perhaps the most challenging issue in the integration of SE and SAT is one of culture, establishing a multi-functional team of such diverse backgrounds and disciplines. It is not easy creating a team of system engineers to address system complexity, architecture, requirements management, platform functionality, networking, synthetic environments and basic project engineering management. Add to this team qualified trainers as well as aircrew, army and naval personnel, all selected as *subject matter experts*, then add the psychologists and human factor engineers and it becomes clear that you need some powerful methods and toolsets to maintain coherency of training output, plus a strong team leader.

Requirements Management

The Architecture Frameworks are good at capturing and communicating requirements, but do not provide the full rigor of Requirements Management (RM) throughout the lifecycle (e.g. traceability). Requirements are normally categorised as customer, functional, performance, derived, allocated etc. In the training domain requirements tend to be described in terms of human performance gaps, task, skill, or even mission essential tasks/competencies. The management of the requirements for traditional SE projects is quite mature, using toolsets such as DOORS, Cradle, CORE (See INCOSE Requirements Management Tools Survey). The same applies to SAT, where training objectives are captured, analysed and traced through to the delivered instruction and the measurement of the effectiveness of the training. However, these two sets of requirements are normally managed by two separate teams and two separate database management systems. Furthermore there is no industry standard toolset for training needs analysis so the Excel spreadsheet is too often used.

The RM of large-scale, complex training systems needs to be improved significantly. The toolsets used for SAT, or Instructional Systems Design (ISD) projects mainly address learning objectives, syllabi and courseware. Such systems cannot manage the collective and coalition mission training objectives, or the optimization of the live, virtual, constructive and classroom training media. The training need, perhaps starting with the operational analysis, but certainly encompassing the Mission Essential Competencies (MECs) (Smith, McIntyre et al. 2007), should be managed in a database management system which provides appropriate analysis, search, query and reporting facilities. The training domain should take best practice from the SE community and establish industrial standard toolsets. Such database management systems are not trivial given the complexity of training objective decomposition and it is not as easy as just adopting one of the Commercial off the Shelf (COTS) standards. However, the benefits of having common toolsets, which would enable the sharing of best practice, re-usability and maintaining a coherent, complete and valid set of requirements, throughout the lifecycle, would be worth the effort. (Firstly, ban Excel for RM!)

Whilst there is much research into SoS and complex systems, most of this is focused at the beginning of the lifecycle, and there is little work on improving RM. If training is going to benefit from a more integrated approach then improved RM systems are needed. Given the amount of data held in such repositories, it should be possible to apply the principles of Information Knowledge Management (IKM) to extract better information, via built in analysis improved search algorithms and modelling capability. For training systems, and indeed other through life, output types services, the RM system should continue to be used for evaluation and measurement of the training effectiveness, overall impact of operational and doctrine change and new technology insertion.

A Systems of Systems Approach to Training Engineering Lifecycle Model

In trying to integrate the points discussed, a high level Systems of Systems Approach to Training (SoSAT lifecycle model can be generated. This is illustrated in Figure 11. The traditions of the Vee SE are inherent in this model, in particular verification and validation. The evaluation of the training, which takes place throughout the lifecycle as a series of maturity phases, is managed via the RM system. The AF underpins the SoS ensuring that the stakeholders understand the operational context, strategy and above all communicate to the end user what to expect. It is maintained throughout the lifecycle to ensure the SoS is always coherent, valid and effective. Above all such SE toolsets are used to ensure that the training system is optimised and the training delivered to the Warfighter is the best possible, at all times.

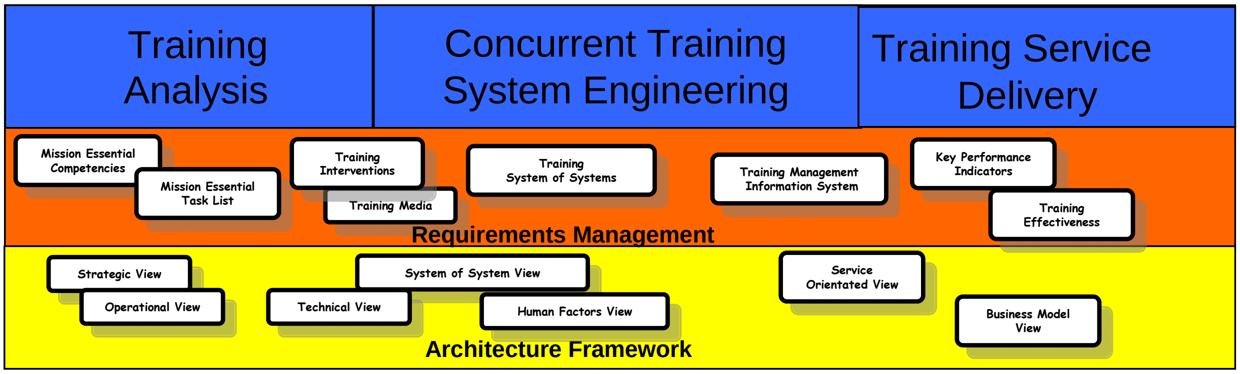

Figure 11 A Training Systems of Systems Engineering Lifecycle Model

Summary

A complex training SoS is needed to allow operators to deliver military effect exactly when required. Such systems embody live, virtual and constructive training systems, with training being delivered in a distributed manner over wide area networks. The "Train as you Fight" mandate creates the need for collective, joint and coalition training, but the NCW assets deployed in war are not easily mobilised for such training. This calls for a greater use of synthetic training, augmented training and other technological innovation. Above all these systems need be designed and developed using the most efficient methods and the training needs to be delivered in the most effective manner.

A Systems of Systems Approach to Training (SoSAT) can greatly benefit from the methodology and knowledge in the systems engineering domain. The benefits of AFs and the more robust RM systems can be used to improve the lifecycle of training. The human dimension inherent in the design of training can be applied to improve SE, in particular to the in-service evaluation and measures of effectiveness.

Training SE can be improved by harmonising the best practice from the SE and SAT domains. However, given the complexity of a SoSAT a more substantial RM system is needed than is usually used for the SAT, or indeed SE. Even so, by underpinning the training system engineering lifecycle with an AF and a RM System the Warfighter would benefit from a more user centric solution.

Finally, we must stop looking at training as an isolated activity, but rather as a fully integrated part of military capability along with other defence lines of development. Only a SoSE approach can allow us to understand and model the complex interactions.

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Biography

David Parkinson graduated in Electronic Engineering in 1971 and joined Singer Link-Miles as a design & development engineer. The main area of responsibility was in the design of computer interfaces and simulation sub-systems for flight simulators (e.g. computer graphics, radar and cuing systems). He was appointed Technical Director in 1985. Notable achievements were associated with the introduction of new computing architectures using microprocessor technology, for which the company received the Queens Award for Technology.

He joined BAE Systems in 1998, with particular responsibility for the engineering development of the Hawk Synthetic Training System.

In 2005 he was appointed Head of Training for Customer Solutions and Support, responsible for engineering policy and governance regarding customer training. His current position is the Head of Capability – Customer Training for Military Air Solutions, with responsibility for the functional / discipline lead and capability development.

During his 38 years in the training and simulation industry he has presented a number of papers on new technology and training systems to the Royal Aeronautical Society, the Interservice/Industry Training, Simulation and Education Conference and the International Air Transport Association.