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User Systems Architectures – Two studies in design and assessment

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ABSTRACT

The concept of User System Architectures (USA) is introduced as part of the overall systems architecture. A USA is defined as a set of ergonomics information and knowledge assembled to represent system structure and content. It is described in the context of the system development lifecycle. The characteristics associated with a USA are outlined. These include layers of description, viewpoints, coherency and traceability. The concept of coherency between layers and the techniques for tracing the design characteristics back to the requirements (i.e. traceability) are discussed with their implications for ergonomics. Two studies (one design and one assessment) are used to demonstrate the use of USA techniques. The benefits, shortfalls and costs of using the USA technique are outlined for each case, and in a more general range of applications. The validity and reliability of the representations are discussed.

1. Introduction

The concept of architecture as expressed within a systems development context e.g. as expressed within MoDAF (MoD Architectural Framework) MoDAF (2009) is used widely. Systems architectures are assembled to represent physical, behavioural and information/communication systems. Hence the phrase User System Architecture (USA) is introduced to refer to that portion of an overall system architecture which presents the structure and content of the ergonomics information and knowledge supporting the development, of the product or service, expressed in a form that is comprehensible and beneficial to the designer and user communities.

MoDAF is closely linked with ISO 15288 which describes the development lifecycle for products and services. It includes the development of a system's architecture as a subset of its processes. ISO 15288 in turn is linked with ISO 26800 which addresses systems ergonomics issues within development projects.

There are already examples of systems architectures within the ergonomics literature which are assemblies of ergonomics information for major engineering projects. They are exemplified in railway systems by Nock et al. (2014), railway automation by Dadashi et al. (2014) and motor vehicles by Michon et al. (1990). Major computer based system developments have been reported to indicate how the architecture of the system reflects requirements and user needs (Roth et al. (2006)). However none of these or others provides guidance in support of a general systems ergonomics approach, to the development and use of USAs.

This paper provides a brief introduction with two studies to illustrate USA principles one from an Armoured Fighting Vehicle (AFV) design and the other from a COntrol of Major Hazards (COMAH) assessment project, in order to provide details on how USAs have been developed and used. Consideration is given, in each case, to the benefits, limitations and costs.

It is intended that these studies will help provide support for a more general approach to the development and use of USAs with associated benefits to stakeholders.

In practice a USA can be developed as a functional description which is:

- Valid as a result of taking a comprehensive approach to description, involving coherent layers and appropriate viewpoints.
- Open to assessment against objective criteria, and hence is reliable i.e. the same description will be produced on different occasions or by different assessors.
- Supports ergonomics activities throughout the development lifecycle including assessment studies.

2. The system development life cycle

ISO 15288 provides a starting point for the concept of a system development lifecycle. This is presented with four sets of processes:

- Technical (to turn requirements into a product or supply of services);
- Organisational (project management);
- Agreement (contract for acquisition and supply);
- Support (including human resources and quality).

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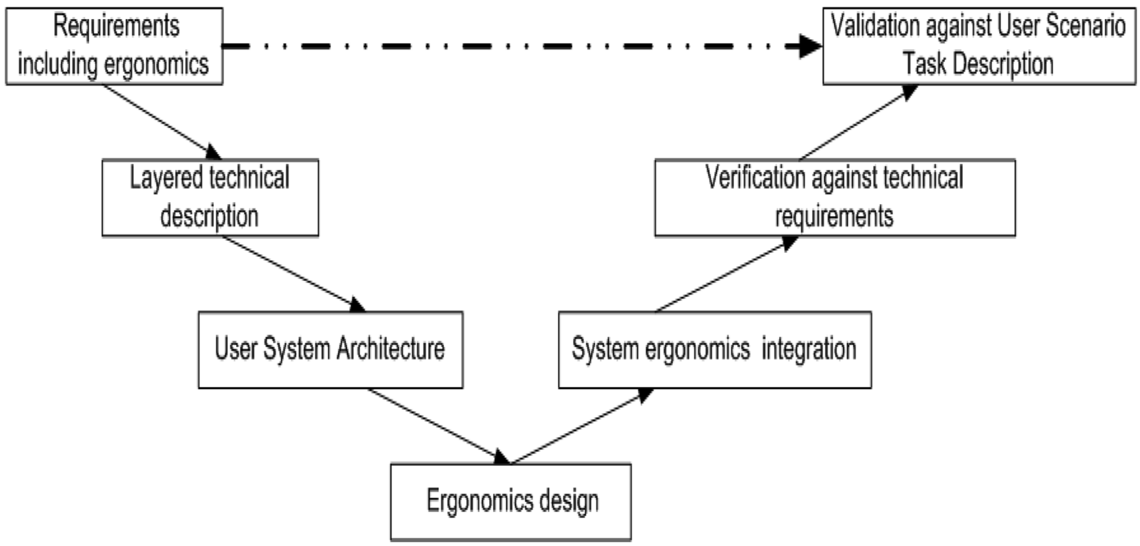


Fig. 1. "V" Diagram for ergonomics contribution to System Development Life Cycle.

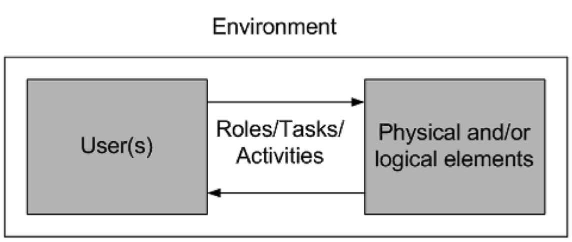


Fig. 2. System interaction as represented within ISO 26800.

The technical line is presented in the form of a "V" diagram. It is presented in Fig. 1 as a high level view of the ergonomics contribution within the system development lifecycle.

The technical process is specified in ways that are independent of implementation but all four may be dependent upon one another. The combination of four sets of processes and the stages within the "V" diagram help ensure a comprehensive approach.

However, these concepts have not been widely reported by ergonomists even though they are potentially useful in a general context, and open to development.

3. Layered system description

ISO 26800 provides an initial high level system description for ergonomics which fits into the lifecycle "V" diagram. It has four elements:

- User
- Equipment
- Tasks
- Environment

The relationship between these elements is interactive and hence they may be represented as in Fig. 2 where the main sets of interactions are between the users and the physical and/or logical elements within the context of an environment (physical or organisational). They are all important as if there are omissions then the validity of the description will be partial.

The "whole system" includes all elements. However large systems may be considered to be composed of smaller systems e.g. vehicles may have power systems, heating and ventilation systems or others. This gives rise to the concepts of "systems of systems" where each sub system may be considered to have its own lifecycle, system description and architecture.

Early stages of the project will include the development of layered descriptions (Winter and Fischer, 2007) which may cover all elements from the viewpoint of many disciplines which impact upon the user (Tainsh, 2013). The layers will be specified to meet the needs of the development lifecycle – typically with increasing accuracy and precision as the project develops. They will be populated with information as it becomes available. The description is a necessary prior stage to the specification of a USA.

Layers are sets of information which represent viewpoints of the system relevant to the User. Initial viewpoints may include (Nock et al., 2014):

- Strategic – requirements (including scenarios)
- System – a combination of equipment and users at work
- Technical – there may be a number of layers here to cover jobs, roles, tasks and activities, facilities, and equipment with various levels of technical detail or other characteristics.
- Assessment – techniques related to the criteria associated with the system/technical implementation and the techniques for assessment.

Within layers, there may be sub-layers – dependent on the characteristics of the system and its subsystems and the needs for the representation. All the layers and sub layers contain sets of representative information and knowledge.

The highest i.e. the strategic layer is adjacent to the requirements and represents the "what must be achieved with the adjacent layer indicating the business system which must work to achieve the strategic goals. The System layer presents a viewpoint on the system to be created to support the work of the business, with the Technical layer showing the contributions from the various sets of work that needs to be integrated within the system layer. Finally there may be a base layer which contains the information on the assessment techniques for the technical layer.

There may be viewpoints which cut vertically across layers. These might include e.g. communication or responsibility. Hence one might have a viewpoint associated with a class of devices or organisational entity, or role or task.

The concept of Layers should not be confused with the concept of hierarchies such as may be used in psychology to describe abilities or personality. "A Layer" is an organisational concept defined by a set of rules to determine which items of information and knowledge may or may not be included within it. A hierarchy of performance descriptions,

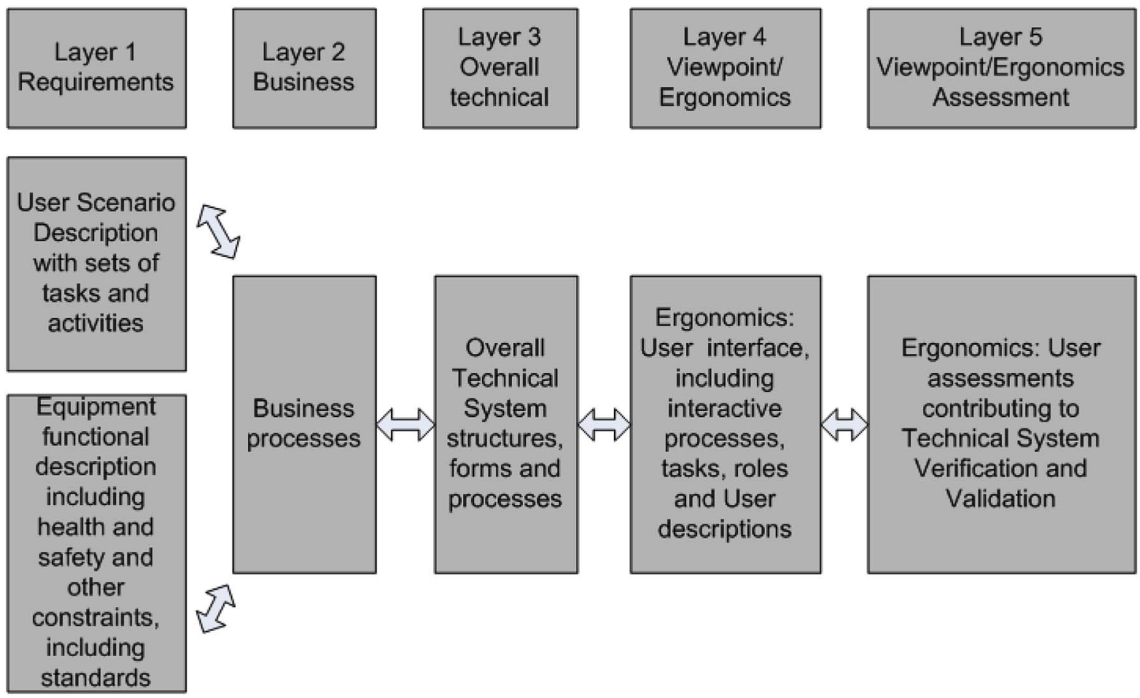


Fig. 3. Generic USA showing possible categories of information in Layers.

tasks, skills or abilities may be included within the ergonomics portion of the technical layer or sub-layer.

It is critical that there is a common means of representation across all disciplines. Initial properties for an effective layered description include the following (Tainsh, 2014):

- Easy to understand by Users and other stakeholders (Bouchard et al., 2005; Lawson, 1979)
- Uses common concepts across disciplines for descriptive purposes, including a common language of expression i.e. vocabulary and syntax (Tainsh, 2014)
- Layered description to enable life cycle characteristics to be placed into a framework (Winter and Fischer, 2007)
- Ease of documentation
- Maintenance and reuse of architectural information

The descriptions required must satisfy the needs of:

- All the disciplines contributing to the project
- Throughout the Life Cycle

MoDAF specifically avoids making a distinction between the characteristics of elements (e.g. users and equipment) and therefore does not handle Target Audience Descriptions (TADs) or other statistical means of characterising the user or maintainer populations.

4. User System Architecture (USA)

4.1. The framework, its structure and content

Starting from concepts introduced with approaches such as MoDAF, it is proposed that a USA is a structured set of system information and knowledge representing a set of User Viewpoints. It is populated to support design or other lifecycle processes. The structure and content varies with application. The structure arises from the number of layers and viewpoints while the content depends on the development. However, the USA should have a minimum requirement to support traceability of the User characteristics to the requirements or other high level goals. Hence, in generic form, it has five layers (Fig. 3).

The design goal for a USA is to represent systems ergonomics information and knowledge in a form that supports the understanding of systems ergonomics requirements including design, integration and assessment, in a form that supports the designer and user communities.

The generic USA is derived using a combination of:

- System concepts from ISO 26800 and ISO 6385 which emphasises work systems;
- Generic architectural concepts from MoDAF or other enterprise architecture standards which describes the logical relationships and naming conventions that apply.

The system representation presented in ISO 26800 can be developed into a USA framework representation as shown in Fig. 3 (Tainsh, 2013, 2014). The representation shows the categories of systems ergonomics information that might be held within a generic framework, within each layer. The arrows show the points where there may be links between the various Layers of information.

4.2. The content of USA

The content is entirely dependent on the application and may represent:

- Documentation – showing the policies, codes of practice, technical specifications, work instructions;
- Organisational characteristics – showing management board, divisional arrangements, working sections, individuals;
- Locations and physical characteristics – showing sites, facilities/plant, individual items of equipment;
- Work teams and members – showing tasks, interaction/communication between individuals and other team members;
- Manpower levels, roles and competency requirements for employees.

Table 1
Traceability assessment framework.

	Degree of traceability achieved across Layers		
	High	Medium	Low
Standards, Regulations	Complete compliance with all standards and regulations.	Compliance with some of the standards and regulations. Non-compliances may be examined with cost benefit analysis to develop a way ahead.	Little compliance with the standards and regulations - these highlight the need for additional work
Categories, Priorities	Complete match of priorities	Some priorities met, amendments will be required.	Few priorities taken into account. This appears as in need of a complete re-examination.
Functional decomposition e.g. of user tasks or operations	Description at each layer completely fits the high layer description	Some match of descriptions. Descriptions improved as required.	Few matching descriptions. This may call the descriptive technique into question.
Communication	All communications flow without the introduction of noise or delay.	Little noise or delay. Adjustments made as required.	Very noisy and much delayed, need for complete re-examination.

4.3. USA characteristics

Again based on MoDAF and similar, the architectural approach includes the following characteristics:

- Layers – There may be a number of Layers (Urbaczewski and Mrdalj, 2006; Winter and Fischer, 2007). These are sets of information that are coherent between one another. The highest layers will reflect the requirements and the lowest the assessment issues. The number of layers and the categories of information held within each layer will be influenced by the desired scope of the framework. The design intention will be to ensure that each layer is comprehensible to the stakeholders and contributes to future stages of the lifecycle.
- Viewpoints – A viewpoint can be any set of information that has meaning from a User perspective. The Viewpoints will vary greatly depending on the product or service. In systems engineering they may reflect components (e.g. input and output devices) or activities (e.g. lifting or transporting) or organisational roles (e.g. management, supervisory, operator or maintainer). Viewpoints may be defined in terms of more than one layer or parts of a layer.
- Coherency – This refers to the relationship between the categories of information held within each Layer. The information in one layer must have a meaningful relationship with the information in the layers above or beneath. The meaningful relationship may be expressed in logical or functional terms. The Layers must be coherent with each other or else it will not be possible to investigate the traceability of the design solution. Coherence is a characteristic of the relationship of one layer to another. Traceability is a general characteristic i.e. is the characteristic traceable from the lowest layers up to the appropriate requirement.
- Traceability – It will always be necessary to trace the characteristics of layers of information and knowledge, from the lowest layers up to the highest (e.g. the requirements or policy) as part of many ergonomic assessment processes that are performed throughout the lifecycle. Ensuring the traceability of one layer to another is important, and in the case of design the implementation of the design to requirements will be part of the verification and validation processes (Tainsh, 2016).

4.4. Traceability

4.4.1. The concept of traceability

It is critical to assess the support to the user scenario or requirements which is given (in the case of 3 Layers) by:

Contribution from Layer 3 $\mapsto$Layer 2 $\mapsto$Layer 1.

"$\mapsto$ "is the symbol which signifies "is mapped onto".

The mapping may be achieved in a number of ways which include:

- Assessment against criteria (standards, regulations) – the matching of the characteristic against the criterion measure;
- Set membership (categories, priorities) – the objects on one layer are members of a set named at a higher layer;
- Functional relationship (decomposition) – the function at one layer is part of a broader function at a higher level;
- Network (communication) – the set of tasks/function provides a medium through which a message can be traced which is independent of the tasks.

4.4.2. The assessment of traceability

The assembly of a USA enables an assessment of the degree to which the information held can be traced back to the requirements or other high level goal.

The degree of traceability of a solution depends on:

- The coherences between the layers of the USA. Hence it is important to examine the description to ensure that the boundaries between layers enable traceability to be inferred e.g., if one layer describes tasks, then its adjacent layer should also hold task related information. If the layered description is completed poorly then it may be difficult to show traceability e.g. if one layer describes a location then the next should not hold task information, but location related information
- The characteristics of the design option and the degree to which they meet the requirement

The degree to which the traceability is achieved may be seen as an indicator of the success of the current design i.e. the degree to which the design characteristic meets the requirement in accordance with the assessment technique.

The degree to which traceability is achieved by a specific design characteristic may be assessed using an assessment framework as shown in Table 1.

Traceability characteristics may be used to show compliance with requirements in design studies or flow of tasking and responsibility in others. Its meaning depends on the content of the USA, its layers and viewpoints.

4.4.3. Validity and reliability

The set of layered descriptions may be applied to each of the elements specified in ISO 26800 or a subset of them depending on the application. The validity of the description will depend on the relationship between the description and the USA requirements. The reliability of the description i.e. the degree to which it will be generated identically dependent on the assessors and the information available, will depend on the techniques used by the assessors – objectively defined criteria and independently gathered ergonomics information will lead to the highest levels of reliability.

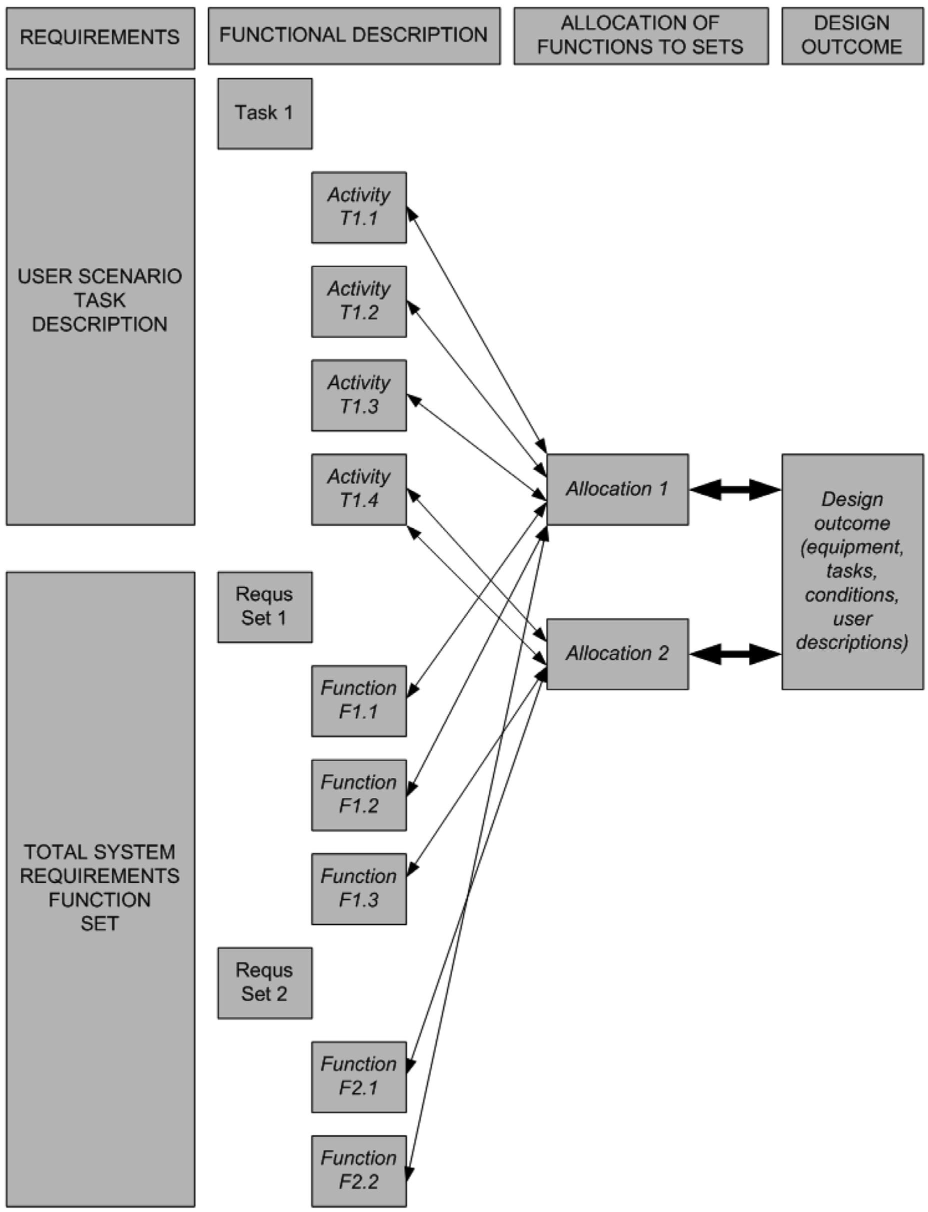


Fig. 4. The allocation of functions into sets for a two person AFV turret. The arrows represent flow of allocation as part of an iterative process.

5. Study 1-design of turret for Armoured Fighting Vehicle (AFV)

5.1. Contribution of early studies

Early investigations of possible system descriptions were carried out to generate an initial high level view of options for design characteristics. Three main processes were included:

- Identification and allocation of functions to elements of the system;
- Assessment of design options against requirements, including risk analysis;
- A development of detail in the understanding of the elements of the system, and the ways that they might impact upon each other, i.e. systems integration. These depend on a high level of coherency between the layers of the description.

5.2. Identification and allocation of function

Initial work used an analysis of the requirements, and User Scenario Task Description (USTD) (Tainsh, 2013, 2014) to generate a list of functions. ISO 15288 emphasises the importance of understanding the functions to be implemented and the process of allocating functions to elements and sub-elements of the overall system. It specifies that in the early stages of design no decisions should be made about the nature of the equipment or personnel, or the balance between the two – early consideration should be free of implementation issues. It is only as results from studies become available, that decisions should be made.

5.3. Developing design options aided by a USA

The process of design development was guided as presented in Fig. 4. This may be considered as a "V" diagram. The design process starts from the identification of a "Total System Requirements Function Set" which will be made up from subset of functions from multiple sources. These are independent of implementation. Design options for personnel and equipment are generated by allocating functions into sets. The sets of functions will need to be implemented in terms of materials, software, communications and personnel. The resultant implementation will need to be able to satisfy the tasks, and activity sets required of the USTD. The design options take account of the User roles

Table 2
Layered Description for AFV Turret System showing viewpoints for functional characteristics, equipment, environment and TAD.

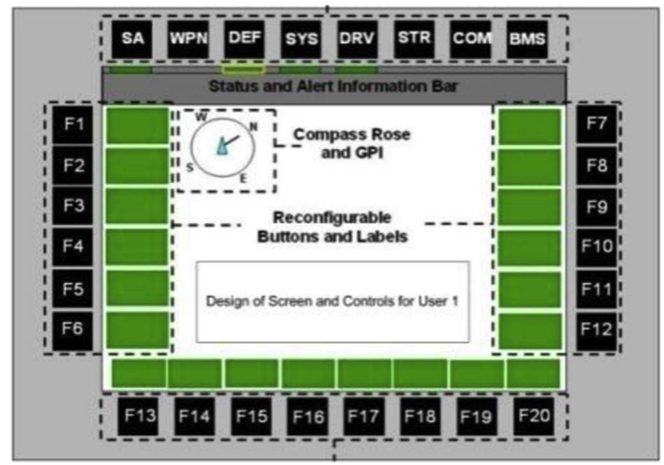
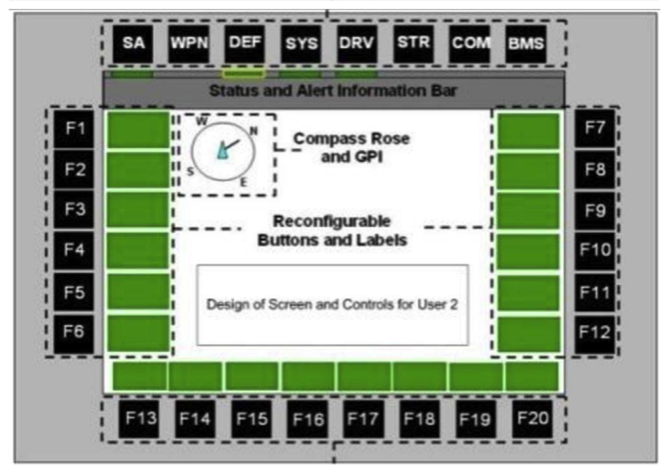
Layer 1	AFV Requirements					
Layer 2	AFV Turret User Characteristics					
Layer 3	Functional Viewpoint			Equipment viewpoint	Environmental viewpoint	TAD viewpoint
	Allocation of sets of functions Set 1	Characteristics of Tasks from USTD Task 1 Activity T1.1 Activity T1.2 Activity T1.3	USTD Task Performance Characteristics Level of Performance Error Rate Operability level	Equipment Characteristics (based on DEFSTAN 23–09)  	Environmental Characteristics Temperature/Humidity Spatial Arrangements Noise/Vibration	TAD for Roles User 1: Commander
	Set 2	Task 2 Activity T1.4	Level of Performance Error Rate Operability level	 	Temperature/Humidity Spatial Arrangements Noise/Vibration	User 2: Gunner

Table 3
The outcome of row characteristics impacting on column characteristics for some ergonomics viewpoints.

	User Characteristics	Equipment Design Features	Task Characteristics	Performance Criteria	Environmental Requirements	Hazards
User Characteristics		Change design	Change task	Change criteria	Change requirements	Improve personal protection
Equipment Design features	Change user/train/select		Change task	Change criteria	Change requirements	Change alarm procedures
Task characteristics	Change user/train/select	Change design		Change criteria	Change requirements	Reduce user role
Performance Criteria	Change user/train/select	Change design	Change task		Change requirements	Reduce need to carry out task
Environmental Requirements	Change user/train/select	Change design	Change task	Change criteria		Improve environmental conditions
Hazards	Improve personal protection	Change alarm procedures	Reduce user role	Reduce need to carry out task	Improve environmental conditions	

and TAD of the job holder.

The allocation process started from a consideration of the Total Systems Requirements Set and USTD. These reflected legal, policy and contractual conditions. The system requirements were grouped functionally into sets (as shown with Requirements Sets 1 and 2) and then allocated for design purposes – shown as Allocations 1 and 2, where in turn they may have implications for two turret roles: Gunner and Commander. This allocation process progressed iteratively as the design was developed. The double headed arrows represent flows of allocation and the fact that the specification of sets influenced the design of the equipment and the Users' tasks including the USTD. Equally on occasion the requirements set was refined.

The design options including both equipment (based on DEFSTAN 23-09) and tasks were assessed using a combination of impact and likelihood (i.e. risk assessments). (See Table 2).

5.4. System integration

5.4.1. Technical goals

The concept of integration depends on a concept of fit. It was necessary to achieve an effective fit between system elements. Until some initial work has been carried out on description, architecture and design, it was difficult to investigate integration usefully. Through a variety of techniques matched to the application it was necessary to consider the relationship of the ergonomics characteristics from all relevant viewpoints:

- One upon another and
- On non-ergonomics variables.

Integration was addressed in two ways: across layers, and within layers.

Integration across layers was achieved through the consideration of the relationships of adjoining layers (or portions of them) to meet the USTDs and the technical requirements.

Integration within layers was achieved through a consideration of system elements or viewpoints within a single layer.

5.4.2. Integration across layers

Prior to the consideration of integration across layers, the specification of the layered description was checked for:

- High degrees of coherence between the specifications of the layers.
- Potential for ensuring traceability.e.g. .it will be clear whether a design characteristic can be traced back to the requirement or not

Work on the integration across layers was to ensure that functions described at one layer can be integrated so that the function at the higher level can be executed successfully e.g. three activities can be combined into a task that can be carried out by a competent user to appropriate levels of performance without unmitigated hazard.

5.4.3. Integration within layers, across viewpoints

The starting point was an assessment of the impact of design characteristics upon one another within layers.

A possible set of considerations for a set of ergonomics viewpoints in a single layer is shown in Table 3. This includes hazards as might be addressed within a safety assessment.

The possible outcome of trades between ergonomics and related viewpoints is shown to illustrate how trade off studies were conducted, and how sets of variables needed to be changed to ensure that a single requirement is satisfied. This may be typified by representing the rows as values which are "fixed" for the purposes of the study, and the columns which are "open" to change (Tainsh, 2013). A possible means of resolving any issues arising because of the need to trade is shown in the cell. These are not intended as definitive courses of action, but rather indicators of how the trade off studies were carried out: considering one variable and its impact on others and potential outcomes.

6. The costs and benefits of developing and handling a USA during a product design project

The benefits associated with the use of a USA within the system development include:

- The USA supports initial studies of design risk, and integration both within the sets of ergonomics information and between ergonomics and other contributing disciplines. This is particularly important for applications such as AFVs where spatial arrangements will be considered in detail throughout the development cycle and any potential non-compliances need to be signalled as early as possible to avoid expensive reworking.
- In order to understand risk, there was a need to trace design decisions back to requirements to ensure that trade-off studies could be carried out in an informed manner. Once again spatial arrangements, including working positions and posture were frequently under consideration.
- Because of the nature of this system design coherency between layers was straightforward – there was an easily traceable set of relationships between spatial design and spatial requirements.
- The technique supports allocation of function studies by providing a record of the process and enabling early assessment studies. This is achieved by supporting the identification of functions from requirements, supporting understanding of the allocation process and enabling early assessment prior to detailed design work.
- The approach aids assessment of verification and validation, by supporting work on tracing design characteristics back to requirements.

The costs are:

- There is a novel stage in the ergonomics life cycle, but this is a normal part of systems engineering and so brings systems ergonomics into line with current practice.
- There is a cost of bringing information together and maintaining configuration of the USA. However, this serves to bring systems ergonomics into line with current systems engineering practice. Further, it enables trade-off studies, and ensure traceability.

Overall:

- Because the USA was comprehensive, and assessed as valid, design options could be approached with confidence and the results were traceable back to requirements.

7. Study 2–safety assessment of COMAH site

7.1. COMAH safety assessment

HSE state that the safety requirements associated with a product or service may require the Duty Holder to develop a formal Safety Case which may be composed of a set of Safety Assessments. In this study the ergonomics assessments were one part of a major study of a COMAH (COntrol of Major Hazards) site for the HSE Inspectorate (Tainsh, 2017).

The HSE COMAH Regulations (2015) require assessments of the following ergonomics characteristics:

- Organisational characteristics (including hazard management practices)
- Roles (including competency)
- Tasks (including personnel responsibilities and risks)

These ergonomic aspects were also considered with respect to the hazards and current mitigation procedures. In COMAH inspections, HSE require the examination of systems documentation prior to examining the current work practices. The example described here with the tables is taken is from a recent investigation into a major hazard environment as required by HSE (Tainsh, 2017).

The architecture was developed starting from the general statement in Fig. 3, and then work was carried out to identify layers of description: requirements, senior management organisation, management organisation, work teams, employee work, and standards.

The USA developed here was a comprehensive framework with three interlinked portions. Table 4 shows the initial set of layers and viewpoints describing the organisational information, with Tables 5 and 6 added to provide detailed information on competency and risk assessment. Table 7 was standalone, and was used to illustrate outcome scenarios.

The assessment started with an examination of the current documentation architecture. This was used to populate Table 4. The viewpoints defining the columns were identified from HSE requirements and the need to provide detailed information on competency, tasks and hazards with their mitigation.

Table 6 shows the way that competency was handled. The information provided in Table 6 is based on the information taken from the UK National Careers Service (2016). This competency information was then linked into the USA as shown in Table 6.

The scope of the USA was determined by the need to include all risks that the COMAH Inspectors need to address, and the need of the Duty Holder to reduce risks to levels that are As Low As Reasonably Practicable (ALARP). The high level view of the USA provides a summary statement to aid HSE comprehension of the scope, content and structure of the ergonomics assessment.

It was necessary to describe accident or incident scenarios. In these

Table 4
User Systems Architecture for ergonomics, hazards and hazard management system documentation.

Layer	Viewpoint - Documentation	Viewpoint – Organisational Responsibilities	Viewpoint – Individual Roles/Competency	Viewpoint/Sites, Buildings and Facilities	Viewpoint - Equipment
Layer 1: Legal Requirements and Policy -	Legal documents, standards and references	Organisational functional description with responsibilities	Competency management policy	Deeds, maps of sites and facilities	Specification of major installations and standards.
Layer 2: Senior Management levels	Codes of Practice and Work Instructions based on legal and policy requirements	Board responsibilities including setting of goals, approving jobs and tasks.	Management of Competency Management Systems	Description of sites, building and major facilities,	Description of major items of equipment with design standards
Layer 3: Site/Facility Management levels	Descriptions of sites and facilities taking account of physical and chemical hazards, and ALARP criteria	Management of safety policy and application to project plans, jobs and tasks	Handling of Competency Management System including roles, jobs and training	Safety/risk assessment of buildings and major facilities, detailed hazard descriptions and management	Safety/risk assessments of equipment and project tasks to be undertaken by users and maintainers.
Layer 4: Employee Work system levels	Detailed Work Instructions, including legal, safety or other compliance requirements,	Execution of project tasks by teams and individuals, with hazard mitigation according to work instructions	Execution of learning/training programmes, and participation in learning and training	Execution of maintenance and upkeep tasks	Use of equipment in accordance with instructions and supervision
Layer 5: Assessment	BS OHSAS Standard 18001	Terms of Reference, management and project plans and statements of competence.	Competence accreditation and certification	Architectural and environmental assessments	Usability assessments including user and maintainer performance failures.

Table 5
Hazard and risk analysis, with mitigation and ALARP conclusions.

	Viewpoint/Sites, Buildings and Facilities. Equipment	Hazards	Mitigation techniques	Cost/Benefit of design changes	ALARP assessment
Layer 2: Senior Manager	Deeds, maps of sites and facilities, major items of equipment				
Layer 3: Manager	Description of sites, building and major facilities, major items of equipment				
Layer 4.1: Supervisor	Safety/risk assessment of buildings and major facilities, detailed hazard descriptions and management				
Layer 4.2: General Worker/ Technician	Execution of work including maintenance and upkeep tasks, and handling of subcontractors				
Layer 5	Architectural equipment, management, individual and environmental criteria				

cases the User descriptions (including competencies) were used with the organisational, role, task and hazard information to predict possible outcomes. All this information was held within the USA.

8. Benefits of safety assessment technique

The benefits of using USA techniques to support this safety assessment were:

- The USA approach with an emphasis on viewpoints fitted the HSE requirements.
- Stakeholder involvement of management, employees, engineers and HSE. There is no doubt that all the stakeholders considered this structured approach as beneficial and helped them be involved. Specialist employees came forward offering content information, the management obtained a clearer understanding of the work for which they were responsible, and the engineers gained a clearer understanding of the hazard management process with the ALARP assessments. The HSE Inspectorate reported that it helped them understand the scope of their inspection.
- The characteristics of coherency and traceability needed to be considered with care here, especially for the organisational characteristics. Organisations have complex reporting and management structures that need to be made clear for the purposes of inspection. In this case the structures were simplified and presented in a hierarchical manner. This aided coherency between layers of description. It also appears to have helped managers understand the totality of the organisational arrangements in which they operated.
- There was an improved traceability of responsibilities for all stakeholders.
- The major organisational viewpoints were provided in Table 4, clearly this could have included more but this set was considered as a useful initial position.
- The process of identifying gaps and failures in current documentation and practices was helped by the highly structured approach. Reviews were held where all this information was laid on a large table prior to discussion so everyone had an equal and substantial opportunity to comment on the subjects within their areas of expertise.

The costs were very small as all the information and knowledge was immediately available in a variety of loosely structured sources.

Overall:

- This assessment could be considered as a design study within the later stages of the development cycle, with unacceptable risks (i.e. not ALARP) handled within a design process.

9. General conclusion

The benefits and costs of having a well documented USA are illustrated by these two studies.

Few major projects now would develop without a clear systems architecture whose form would depend on the application. Ergonomists appear to have no well developed body of knowledge to support their contributions although in studies such as COMAH assessments, their contribution may be substantial. The key benefits appear to stem from a structured approach using layered descriptions and viewpoints which depend on coherence and enable traceability.

Overall the approach was seen to have been effective. It enabled stakeholders to understand the ergonomics contribution and the means of integrating it with their own, and vica versa. The costs of the work were not estimated but appeared minimal with respect to the overall cost of the project, and outweighed by the benefits.

The costs of not having an architecture may come late in the project when requirements are being examined (in design) for verification and validation (which are forms of assessment), or coming to incorrect conclusions in assessment studies as a result of an inadequate consideration of the information that is available.

This paper only describes initial considerations on how USAs might be used and developed. As the discipline of ergonomics develops, we may expect the concepts to become more specific and a greater understanding of the validity and reliability of the descriptive techniques.

The validity of the descriptive technique depends on a comprehensive approach in line with ISO 26800, coherence between layers of description, and the use of ergonomics information which can be checked against objective criteria. Equally the use of objective criteria will help ensure the reliability of the representation.

The methods and techniques associated with the development and use of the USA for design and assessment purposes directly influence the outcomes of any study. Hence it is important that:

- The USA can be assessed for validity and can be developed with a high degree of reliability.
- The approach is based on requirements and is comprehensive, this is important in design where it is essential to have traceability of results. This ensures that where there is a difference between “requirement” and “as designed” an assessment can be made such as ALARP to ensure that the difference is acceptable.
- The emphasis on early design work will support subsequent systems integration and acceptance.
- An understanding of requirements and standards can be linked to verification and validation criteria such as ALARP, which, with a knowledge of traceability will aid understanding and trust in the design and assessment outcomes.

Table 6
USA Viewpoint on Competency characteristics in line with levels specified by National Careers Service.

	Board responsibilities including setting of safety goals, jobs and tasks. This includes independent safety scrutiny.	Professional Learning/Training/Qualifications	Facility/Equipment Experience	General Safety Training
Layer 2: Senior Manager	Management of safety policy and application to project plans, jobs and tasks	Graduate or equivalent with appropriate professional experience (Level 7)	Substantial management experience	Appropriate to working environment.
Layer 3: Manager	Execution of project tasks by teams and individuals, with hazard mitigation according to plan and work instructions	Graduate or equivalent with appropriate professional experience (e.g.3/4 years mentored experience). (Level 7)	Between 6 months to two years' experience on a facility and its associated equipment, or groups of equipment.	First aid, manual handling, working at height etc. as appropriate.
Layer 4: Supervisor	Terms of Reference, management and project plans and statements of competence.	ONC, HNC or equivalent with appropriate professional experience (Levels 5 or 6)	Between 6 months to two years' experience on an item of equipment. Capable of supervising others with advice of Manager.	First aid, manual handling, working at height etc. as appropriate.
Layer 5: General Worker/ Technician	Board responsibilities including setting of safety goals, jobs and tasks. This includes independent safety scrutiny.	Little specific professional or academic training. (Levels 2 to 4)	Trained to operate specific items of equipment and carry out tasks as required.	First aid, manual handling, working at height etc. as appropriate.

Table 7
Safety Process Chart for hazardous event at COMAH site.

Roles	Scenario		
	Time Period 1	Time Period 2	Time Period 3
	Activity	Activity	Activity
Senior Manager	Set safety goals		
Manager	Develop project plans including handling hazards		
Supervisor	Manage work systems		
Technician	Carry out training and work		
Hazardous material	Be recorded on lists, associated with appropriate standards	Hazardous material and initiating agent brought together with severe outcome	
Initiating agent	Handled in accordance with standards		
External groups			Take precautionary actions
Emergency services			Attend site with ambulances and/or other.
News media			Disseminate information.
Central Agencies			Record and assess so that policy may be influenced

Practitioner summary

The concept of a User System Architecture (USA) is introduced within the context of the system development lifecycle. Its use is illustrated with two studies. Benefits, shortfalls and costs are discussed for each case, and in general.

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