A Tool to Generate 'HF Meaningfulness' in the Design and Development of Armoured Fighting Vehicles

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Abstract. The design and development of Armoured Fighting Vehicles (AFVs) at Lockheed Martin UK Ampthill (LMUKA) takes a Systems Engineering approach and incorporates many engineering disciplines. One of these is Human Factors (HF), which contributes to a number of other disciplines. To support this contribution and to generate 'HF meaningfulness' the LMUKA HF Team developed the Systems Engineering Comparison Technique (SECT). The SECT takes a User Centred Design (UCD) approach and incorporates the pairwise comparison technique developed by Thurstone (1927). The main aim of SECT is to take subjective scores and generate objective scores that can be used by Design Engineers and Engineering Leads for improving the design of AFVs. This is done by highlighting the design strengths and weaknesses, which are then fed into future design iterations.

Keywords. Armoured Fighting Vehicle; User Centred Design; Pairwise Comparison; Subjective Scores; Objective Scores; Design and Development.

1. Introduction

Within Lockheed Martin UK Ampthill (LMUKA) the Human Factors (HF) Team is treated as a Systems Engineering discipline. The overall goal of Systems Engineering is that all engineering activities are united and are working towards the same result, ensuring compliance against System Requirements (SRs). This inter- and multi-disciplinary approach is prominent in the definition of Systems Engineering provided by the International Council on Systems Engineering (2016). In this it describes the defining of SRs, the integration of disciplines and specialty groups as part of a structured process, design synthesis and system validation, and the consideration of the 'complete problem'. The complete problem is defined as: operations, cost and schedule, performance, training and support, test, disposal, and manufacturing.

The LMUKA HF Team continuously work with Systems Engineers to overcome challenges and design and project constraints in an effort to produce a coherent and effective product / solution. A prominent role the HF Team has is in the design and development of Armoured Fighting Vehicles (AFVs). The HF Team provides guidance and support to the different engineering elements of AFV design including: guidance on the physical characteristics of Users; and support on the design and development of Human Machine and Human Computer Interfaces (HMI / HCI).

During the early stages of AFV design the LMUKA HF Team worked alongside project Engineering Leads to ensure HF-related SRs were flowed to the relevant aspects of the design. As the project progressed, and taking into account the question asked by many Design Engineers towards the HF Team of '*How do you know when you're done?',* it became apparent that a process was needed to demonstrate how compliant the AFV design was to HF-related SRs. HF minds from LMUKA and business associations came together to provide a potential solution to the query and to generate 'HF meaningfulness'.

By 'HF meaningfulness' the LMUKA HF Team wanted to create a method for constructively incorporating HF into the design and development of AFVs in a way that could be related to by Design Engineers and Engineering Leads, as well as Management. Although the method was to demonstrate how compliant the AFV design was to HF-related SRs, the HF Team did not actually own any SRs. This made it difficult for the HF Team to contribute to the design and development of AFVs when Design Engineers and Engineering Leads preferred conclusive outcomes relative to compliance statuses i.e. compliant or non-compliant. HF-related SRs can be overarching and complex e.g. 'system shall be usable by crew and dismounts equipped wearing equipment appropriate to the role', and so make it difficult to provide conclusive outcomes.

So the method created needed to provide conclusive outcomes and meaningful data to demonstrate compliance assurance for HF-related SR rather than a compliance status. Following discussions, the pairwise comparison technique developed by Thurstone (1927) was proposed as a method that could provide objective scores from subjective ratings through a process of weighted scores. The objective scores could demonstrate strengths and weaknesses in AFV designs, and subsequently direct design developments.

This paper describes the tool developed by the LMUKA HF Team that incorporates Thurstone's pairwise comparison technique and generates objective scores. The tool is referred to as the Systems Engineering Comparison Technique (SECT). It is hoped the description of the SECT in this paper will be of benefit to other HF professionals, whether in academia or industry, and that it will help cross the divide with other engineering disciplines.

2. The SECT

2.1 Aims and Objectives

The SECT is User-focussed in its development and in implementation through AFV Mock-Up User Workshops. It shows the progression of compliance to HF-related SRs to Design Engineers and Engineering Leads, as well as the Customer. By doing this it demonstrates the capability of the design of the AFV in accommodating the full range of Users in their various clothing attire (as defined by the Customer) and the capability of Users to perform their full range of tasks effectively and safely. The SECT enables different designs of AFV Mock-Ups to be assessed over a period of time at different User Workshops or for particular features of an AFV to be assessed in one Workshop, where it is possible to vary features in quick succession. The SECT is embedded within LMUKA's Product Design Process, which consists of the following design development milestones:

- System Requirements Review
- System Design Review
- Preliminary Design Review
- Critical Design Review

The SECT is mainly utilised in the periods leading to Preliminary and Critical Design Reviews and consists of five parts, including one that incorporates Thurstone's (1927) pairwise comparison technique:

1) Engineering Specification
2) System Criteria of the Specification
3) Pairwise Comparisons and Weighted Scores
4) Scoring Specification
5) Scoring Spreadsheet

Each of these parts is described below, detailing User involvement in each. This is crucial for the SECT to obtain User validation and approval, and is a means for the LMUKA HF Team to follow a User Centred Design (UCD) approach in accordance to ISO 9241-210: 2010 (ISO, 2010). The UCD approach extends to the implementation of the SECT at User

Workshops.

2.2 Engineering Specification

Initial User involvement when developing the SECT, led by Subject Matter Experts, assists the HF Team in validating and approving the SECT Engineering Specification. The Specification is a list of AFV items to be assessed in the context of User operations and missions including: conducting surveillance through various sights and cameras; or acquiring and engaging a target using hand controls and control panels. Items in the first SECT developed by the LMUKA HF Team focused on the equipment within an AFV that required the Users to view and / or gain access to.

2.3 System Criteria of the Specification

Following User validation and approval of the SECT Engineering Specification, Users are then involved in validating and approving the corresponding System Criteria. Criteria are those aspects of the items directly linked with their performance, or indirectly impacting on User operations and missions. Items will have a minimum of one criterion (a direct criterion), with further criteria depending on the assessed item. From the first SECT, an example of a direct criterion could be viewing distance to equipment e.g. display screen, with an indirect criterion the effect equipment layout has on Users accessing and exiting the AFV.

2.4 Pairwise Comparisons and Weighted Scores

Following 2.3-2.4 Users perform a pairwise comparison. Users first rate the level of importance of the items, and secondly, the level of importance of the criteria. This is done using a matrix table, which means all items and criteria can be compared against each other twice. The level of importance uses five levels:

1) Much less important
2) Less important
3) Equally important
4) More important
5) Much more important

The numerical values for the five live levels are associated with a weighted score, which is based on a pairwise comparison technique developed by Thurstone (1927). Numerical values need to be normalised so all scores can be accommodated and to ensure that values for the category being measured (level of importance in this case) are proportionate for all possible variations in the number of items / criteria. Table 1 shows this, and Table 2 gives an example of how a pairwise comparison for four items / criteria would be done and how the associated weighted value would be calculated (numerical values added to aid example). Microsoft Excel is used to complete the comparison and record the results for each one done for the SECT.

Table 1: Normalised importance level numerical values

Level of importance	Number of items/criteria					
	1	2	3	4	5	6
Much more important	1.000	0.500	0.333	0.250	0.200	0.167
More important	0.800	0.400	0.267	0.200	0.160	0.133
Equally important	0.500	0.250	0.167	0.125	0.100	0.083
Less important	0.200	0.100	0.067	0.050	0.040	0.033
Much less important	0.100	0.050	0.033	0.025	0.020	0.017

Table 2: Pairwise comparison and derived weightings

<table>
<tr><th></th><th>A</th><th>B</th><th>C</th><th>D</th><th>Item/criterion total</th><th>Weighting</th></tr>
<tr><td rowspan="2">A</td><td rowspan="2"></td><td rowspan="2">0.250</td><td rowspan="2">0.250</td><td rowspan="2">0.200</td><td>Sum_A</td><td>Sum_A/Total</td></tr>
<tr><td>0.700</td><td>0.700/1.575 = 0.444</td></tr>
<tr><td rowspan="2">B</td><td rowspan="2">0.025</td><td rowspan="2"></td><td rowspan="2">0.200</td><td rowspan="2">0.050</td><td>Sum_B</td><td>Sum_B/Total</td></tr>
<tr><td>0.275</td><td>0.275/1.575 = 0.175</td></tr>
<tr><td rowspan="2">C</td><td rowspan="2">0.025</td><td rowspan="2">0.050</td><td rowspan="2"></td><td rowspan="2">0.025</td><td>Sum_C</td><td>Sum_C/Total</td></tr>
<tr><td>0.100</td><td>0.100/1.575 = 0.063</td></tr>
<tr><td rowspan="2">D</td><td rowspan="2">0.050</td><td rowspan="2">0.200</td><td rowspan="2">0.250</td><td rowspan="2"></td><td>Sum_D</td><td>Sum_D/Total</td></tr>
<tr><td>0.500</td><td>0.500/1.575 = 0.317</td></tr>
<tr><td colspan="5" rowspan="2">Sum total</td><td>Sum_A to Sum_D</td><td>Approx. 1</td></tr>
<tr><td>1.575</td><td>(when rounding may be slightly less;
0.999 in this instance)</td></tr>
</table>

2.5 *Scoring Specification*

With the pairwise comparison complete the scoring system for the SECT can then be generated. This is carried out by using a five-point Likert scale with statements in the scale relative to compliance assurance. The scale uses the following statements:

1) Unacceptable
2) Falls well short
3) Just short
4) Optimal design
5) Exceeds design requirement

To eliminate subjectivity from the scoring process and to provide a constructive platform for the five-point Likert scale, a Scoring Specification is defined and used for scoring against the criteria in the System Criteria of the Specification. Since the SECT was developed for compliance assurance the LMUKA HF Team based the optimal design score on HF-related SRs, as well as HF practice and standards e.g. British and Defence Standards, and existing knowledge of the AFV.

The optimal score provides the baseline from which the other scores are generated. Some criteria may have requirements that leave little deviation from the optimal score, which may result in some of the scores being noted as N.A. Where this has occurred the LMUKA HF Team has tended for scores of five (exceeds design requirement) and/or three (just short) to be defined as N.A. An example Scoring Specification for a display screen is provided in Table 3. This shows two criteria (Eye level distance; Eye level angle) whose scores have been derived from DEF STAN 00-250 Part 3 Section 9.

Table 3: Scoring Specification for display screen

System Criteria of the	1 Unacceptable	2 Falls well short	3 Falls just short	4 Optimal design	5 Exceeds design

Specification					requirement
Eye level distance	300-350mm	350-400mm	400-450mm	450-500mm	500-700mm
Eye level angle	Display >30° from centreline, both horizontally and vertically	Display >10° from centreline horizontally and 20-30° vertically	Display within 5° of centreline horizontally and 20° vertically	Display central and within 5° vertically	Display central and within 5° vertically, and top of display at eye level

2.6 Scoring Spreadsheet

The Scoring Specification is added to the Microsoft Excel spreadsheet with the pairwise comparison and a User Scoring Spreadsheet is then generated for use at User Workshops. The Scoring Spreadsheet includes: the User scores based on the five-point Likert scale; and the weighted scores for items from the Engineering Specification and criteria from the System Criteria of the Specification. The User and weighted scores are used to generate an overall score for a design being assessed.

When more than one design is being assessed the overall scores enable design comparisons. As said in 2.1, this can occur over a period of time in different User Workshops or in a single one. Table 4 provides an example of a Scoring Spreadsheet for three designs (Design 1 – acting as a guide; Design 2; Design 3), where the designs have three items to be assessed (A; B; C), two having three criteria (A1-A3; B1-B3) and the last having two (C1and C2).

In order to support User scoring and provide rationale for both positive and negative scores a column is included in the SECT for User comments. These are recorded during assessments when Users provide scores. Where scores are lower than the optimum of four the rationale for the scores can assist Design Engineers and Engineering Leads in improving the AFV's design. In the event of scores of five it may be possible that these scores compensate lower scores in future design iterations. This is demonstrated in Table 4 with Engineering Specification 'C'.

Table 4: User Scoring Spreadsheet

Engineering Specification	System Criteria of the Specification	Design scores (1-5)			Weighting	Weighted design scores (1-5)		
		Design 1	Desig n 2	Design 3		Design 1	Design 2	Design 3
A					0.300	(SUM_ X9 to X11)*0 .300 = X17	1.260	1.305
	A1	X1	4.000	4.000	0.500	X1*0.5 00 = X9	2.000	2.000
	A2	X2	5.000	5.000	0.350	X2*0.3 50 = X10	1.750	1.750
	A3	X3	3.000	4.000	0.150	X3*0.1 50 = X11	0.450	0.600
B					0.400	(SUM_	1.040	1.468

						X12 to X14)*0.400 = X18		
	B1	X4	3.000	3.000	0.330	X4*0.330 = X12	0.990	0.990
	B2	X5	2.000	4.000	0.400	X5*0.400 = X13	0.800	1.600
	B3	X6	3.000	4.000	0.270	X6*0.270 = X14	0.810	1.080
C					0.300	(SUM_X15 to X16)*0.300 = X19	1.260	1.200
	C1	X7	5.000	4.000	0.600	X7*0.600 = X15	3.000	2.400
	C2	X8	3.000	4.000	0.400	X8*0.400 = X16	1.200	1.600
Final weighted design scores (1-5)						SUM_X17 to X19	3.560	3.973

3. SECT Results and Outcomes

Results generated at User Workshops are collated and presented in a User Workshop Report. SECT scores are presented in both tabular format (straight from Microsoft Excel) and graphically using bar charts. These enable quick comparisons to be made between designs and it can also be used to compare the full range of Users in their various clothing attire. Reports are supported by User comments and photographic evidence, which help to reinforce the SECT scores where there are design weaknesses and strengths.

The Report is distributed internally to Engineering Leads and Management, and is summarised in Customer Reports. Outcomes from User Workshops are discussed with the Customer at Human Factors Integration Working Group meetings and the outcomes may also support Problem Reports, Change Proposals and Design Reviews. This is where design issues or risks are raised, new designs or features of designs are proposed, and the new designs are reviewed for approval.

Where issues or risks exist that have an effect on usability and operational capability of an AFV, and alternative designs fail to overcome this, then a User Preference Trade (UPT) may be needed. UPTs require consultation with Users to consider the current design proposal and what this means in relation to their related tasks, as well as compliance assurance for HF related SRs. A design trade-off based on User preferences may result if certain designs or features of designs divert from their desired optimal, but Users are satisfied with the overall design's usability and operational capability. It is vital for Management that UPTs are documented, with the documentation disseminated to appropriate parties (in-house and externally) to inform them of the design trade-off, how this came about, and what this means for the Programme, the AFV and SRs. UPTs work to ensure the UCD approach is followed and encourages traceability of design decisions.

4. Conclusion

The LMUKA HF Team wanted to create a method for constructively incorporating HF into the design and development of AFVs in a way that could be related to by Design Engineers and Engineering Leads, as well as Management. The SECT was developed to achieve this by incorporating HF methodology and a UCD approach. Key to this was the pairwise comparison technique developed by Thurstone (1927) and User involvement.

The SECT has proven to be a resourceful tool for providing meaningful data to demonstrate compliance assurance for HF-related SRs in a conclusive manner that assists in the design and development of AFVs. This allows the LMUKA HF Team to drive the design forward by feeding into the evidence documentation compiled to show design progression. The objective scores provide Design Engineers and Engineering Leads with tangible quantitative data that can be used for improving designs, supported by User qualitative data. Where a design fails to meet User expectations UPTs can be used that reinforce the UCD process.

The SECT has been well received by Users and the Customer. The acceptance by Users is crucial for the continuing utilisation and success of the SECT since Users often rotate every two years. For Users new to the SECT the knowledge that previous Users have been involved in developing the SECT (as part of a diligence process) is reassuring and gives it a credibility when used at User Workshops. The structure of the SECT itself provides User Workshops with a structure to follow, which makes it easier, quicker and more efficient (in cost and resource) to conduct assessments. The SECT also lends itself to commonalty and consistency across assessments and across programmes.

The time required to develop a SECT will depend on its complexity but the first SECT developed by the HF Team at LMUKA took about three weeks from generating the Engineering Specification to defining the Scoring Specification. A maximum of six Users was sufficient to acquire the necessary User input. Ideally more time would have been spent with Users, as well as in developing the tool using Microsoft Excel. The more items and criteria there were in the tool the more difficult it became to manage in Excel. So taking the time to correctly configure the tool in Excel in the first instance is recommended so that future adjustments are easy to incorporate.

The aim for the LMUKA HF Team going forward is to have the SECTs contribute to the Qualification and Validation of AFVs. The LMUKA's Integration & Test (I&T) Team carry this out using Test Scripts to collect evidence to prove compliance to SRs. For HF-related SRs the SECTs can provide the I&T Team with a basis for developing Scripts and as a future ambition SECTs could be used as the method for evidence collection itself. This would enable SECT scores to be compared with different design iterations and, as an integral tool in the design and development of AFVs, it could possibly lead to the deriving of SRs to improve User performance and safety. This would emphasise the contribution of the HF Team and would reinforce what is meant by 'HF meaningfulness'.

5. Acknowledgements

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