# Six-sigma reform and education in Australian Defence: lessons learned give rigour and efficiency to ordnance, aircraft and ship testing

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# SIX-SIGMA REFORM AND EDUCATION IN AUSTRALIAN DEFENCE:

# LESSONS LEARNED GIVE RIGOUR AND EFFICIENCY TO ORDNANCE, AIRCRAFT AND SHIP TESTING

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**Abstract**
**Purpose*:*** In 2010 U.S. Defense introduced mandatory use in test and evaluation (T&E) of statistical techniques from six-sigma (SS), including the necessary education and competency for test and acquisition staffs. Australian Defence quickly offered these courses to T&E staff for three years without achieving use of the techniques. However, a new educational and reform approach in the last two years has seen the SS techniques used in several Defence test organisations with benefits in test rigour and efficiency. This paper outlines the lessons learned in adopting SS within a Defence force.

**Method*:*** This longitudinal review of SS reform in Australia's Defence spans six years and leverages a case study in its first official use from 2015, a curricular reform study in teaching SS techniques from 2016, and then six case studies of effective use since.

**Findings:** The review finds that test policy, properly leveraged and powerful as it is in the U.S. Defense, is a change factor that Australian Defence could not easily mimic. Instead, a bottom-up reform was necessary where it was critical for penetration that the right test staff were targetted for attendance, rather than maximum attendance, and that the education included hands-on competence in the classroom, mentored use and assessment back in the workplace, and case study presentation for management.

**Value:** This review is of benefit to any beaucratic organisation hoping to leverage SS techniques. Educators of SS will find key pedagogies reinforced and encoragement to adopt long-term partnering on implementation and culture, rather than simply student numbers.

**Keywords:** Six-sigma, Design of Experiments, Organisational Reform, Curricular Alignment, Test Design, Test Analysis

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## Introduction

Formally T&E is a structured process by which a system or product is compared against technical or functional criteria through gathering data from testing, and evaluating results to assess its fitness for purpose. T&E is usually managed as part of systems engineering and is primarily to identify the areas of risk to be reduced or eliminated. The U.S. Defense mandated statistical techniques from the design of experiments (DOE) and SS stables in its test programs from 2010 (U.S. DoD, 2010 & 2014; Johnson et al., 2012) and they underpinned this with competency-based education programs for all test staffs and associated acquisition staff (Defense Acquisition University, 2015). The efficacy of this visionary effort is in increased rigour, efficiency and accountability, and has been documented by numerous U.S. authors in the T&E domain (Ahner, 2016; Chu, 2016; Kass, 2015; Lednicky & Silvestrini, 2013; Murphy et al., 2015). The methodologies used leverage mainly DOE for test design (Simpson, Listak & Hutto, 2013; NIST, 2018) and then from the fields of lean SS (LSS) for test analysis (Schmidt & Luansby, 2005; Antony, 2014), sampling techniques (descriptive & latin-hypercube) and from design for SS (DFSS) for robust design and tolerance allocation (Reagan & Kiemele, 2005; Rucker, 2014; Joiner, Zahra & Rehman, 2018). More recently the movement has incorporated high throughput testing (HTT) techniques using combinatorial methods to do highly efficient screening or validations, especially of simulations and to do more rigorous software verifications (i.e., Mackertich et al., 2017) and cybersecurity protections (Christensen, 2015; Joiner & Rehman, 2017) with up to six-way combinations (Kuhn et al., 2016; Kuhn, Kacker & Lei, 2010). The U.S. Defense methods have also spread to the U.S. Defense Industry initially for compliance purposes, meaning that these industries are now realising industry benefits (Pulakanam, 2012; Antony, 2014) that were hitherto only commercially motivated.

Joiner and Tutty (2018) have reviewed how such SS rigour in T&E has worked in concert with five other U.S. Defense initiatives to meet four key challenges for integration, interoperability and information assurance (I3 assurance) of modern interconnected systems-of-systems. That research highlighted how Australia, without these six initiatives, are losing pace in integrating with U.S. forces, especially against growing cyber threats (Joiner, 2017). Thus, systematically keeping pace with SS testing is a key element of being a reliable, robust, efficient and credible defence ally. Therefore, the purpose of this longitudinal study was to determine what educational and organisational reform elements of the U.S. DoD SS testing had already worked in Australian Defence and why, so that the pace and efficacy of these reforms could be improved. The characteristics for the study were the number of test agencies using the test techniques and the number of T&E personnel educated in their use. Publishing these results might help other countries impove the penetration of SS testing into their major bureaucracies.

## Early Australian Defence SS Efforts

Australian Defence test leadership sought to leverage the U.S. Defense courses in SS testing, beginning with training of volunteer T&E staff each year from 2012 to 2014. Unlike the U.S. Defense, Australian Defence did not have centralised T&E competency management or T&E policy through which to mandate use, especially for acquisition projects. In 2014 the author organised the first official use of SS testing when he was director general for preview testing of proposed capabilities (Joiner, Kiemele & McAuliffe, 2016). The trial was to determine the most effective ancillaries to enhance performance of Australia's main military rifle. Among the many benefits of using the SS test techniques were the usual benefits of rigour and efficiency especially against the baseline performance, but also the ability to bring together developmental and operational test staffs in shared testing with multiple metrics. Two unexpected research benefits came from that early trial that helped inform project transition: (1) marksmanship was properly tested for the first time in two ouputs of accuracy and timeliness, and (2) the inclusivity of different sub-groups of shooters, such as female and different marksmanship abilities, could be statistically analysed. Such seredepitious research and fresh perspective has been a characteristic ever since in the use of SS testing in each new defence field.

The overwhelming sense coming from the first official use was one of lost opportunity in taking so long to apply the techniques and of a need to 'move out' on policy to facilitate wider use. However, over 60 test staff had been trained in three years with only that one use, so there needed to be a change in direction in the education package and how it was to be applied. Fortuitously, the author was retired and took up this challenge from within the university that leads Australian Defence education.

## Changing the SS Testing Curriculum

The SS test knowledge being taught on early courses was sound and serviced industry and Defense well in the U.S. and some parts of Europe. However, nearly everywhere this course was applied, students would return to a unit or business already using SS testing, and importantly to mentors and policy supporting its use. In Australia, there was no mentoring or prior unit use. So each student would need greater competency before leaving the course and be incentivised in some way to apply the techniques in their workplace with on-going external mentoring. Universities are heavy users of assessment so as to meet standards, establish competence and to motivate students. Therefore, the university subject developed was primarily reformed from earlier courses around the assessment (Joiner & Brewster, 2017).

In the revised SS testing subject students must first follow-along in the intensive teaching week for all test design and analysis exercises and then apply these in collaborative groups to a teaching system for demonstrated competence. Students then have to apply the techniques in their home location, under mentoring from the teacher, as an assessed individual research assignment. Students could choose a hobby or a work-based research topic which then gives them a social interest and Vgotskian medium from which to build more robust conceptions, but also from which organisational awareness usually builds. An example from the inaugural revised subject was a student who set out to quality control the baking of cupcakes. She shared over 500 cupcakes of steadily improving quality with her electronic warfare colleagues. Figure One shows the variety in cupcakes achieved by the low-high factor settings necessary to screen and model the baking.

**Figure 1: Cupcakes from the SS test screen and model (Joiner & Brewster, 2017)**

The cupcake example has since been repeated in other workplaces with topics like the production of spirits, a beer pourer, boiled eggs, video gaming, water-bottle rockets and so forth. Any topic done competently and shared with passion is memorable and potentially influential to workplace penetration of SS techniques!

While students who are the first to undertake the subject from their test units have tended to take hobbies for their topics, subsequent students from their units have found the workplaces more aware and receptive to work-based topics. Often the early work-based research is on historical test data, so students can readily complete the assignment in time and the workplace takes no major risk with new methods. However such historical reviews also help reform, as these usually disclose that test design was inefficient (Henry & Joiner, 2017) or lacking in-depth analysis (Sisson & Joiner, 2018). For example, one unpublished experiment was found to be some 500 percent inefficent compared to a DOE method, albeit there were other complicating operational test objectives. Such findings are a non-threatening learning exercise for the test unit and therefore influential units to properly trial the SS techniques.

Two test units who had students on the inaugural revised subject then invested in dedicated subjects at their units and they have since provided more students. This repeat education business is attributed strongly to the mentoring given to students, sometimes by visiting the units, but also by phone and e-mail. Such mentoring is expected in most university post-graduate assessments. One of Australia's three services has now put SS test competence in test policy and is giving the subject to its network of test officers. This takes the total of test units in Australian Defence actively using such competence to one-third, with traditional flight-test units the most significant areas yet to really try. One aspect to highlight between the pre-2015 and post-2015 efforts is that students are now being placed by their units with a view to reform, rather than for interest. This means there are less officers giving the damning praise, '*Nice course but I've never used it since.*' Such reflections often undermine organisational reform by suggesting low applicability, or worse still unaffordable rigour, and they can be facilitated by '*seat-filling*' on courses with students who have a low prospect of subsequent use. Three test organisations using SS testing are now investing in follow-on education from their early users to be unit mentors.

**Case Studies in a More Enduring Impact**

**Ordnance Testing.** An officer from the inaugural revised subject examined in-service failure data on an artillery flare type and his statistical analysis helped achieve a cooperative fault remedy by the manufacture. Subsequent ordnance test students examined topics such as target effects for bullet wounding (Brooks & Joiner, 2017), new bullet type qualification requirements (Henry & Joiner, 2017) and ammunition testing for ship guns (unpublished). A common finding from historical ordnance test data is that the test design lacks consistency in repetitions, doing more shots at common ranges and less at say longer ranges. Distributing test points according to anticipated use denies orthogonality and weakens the prospect of the testing adequately validating the manufacturers' claims, or of modelling adequately the operational effects. Similarly, suitability testing policies are usually devised to be representative of expected usage patterns, which is potentially wasteful when compared to a designed experiment against declared test metrics.

One case study from the ordnance unit involved using SS analysis to validate and calibrate the accuracy of a new acoustic-based projectile locating system (Sisson & Joiner, 2018). The assessed error in two dimensions is shown (Figure Two). This work has given confidence to use this safer and more efficient locating system for the many weapon natures that it can support.

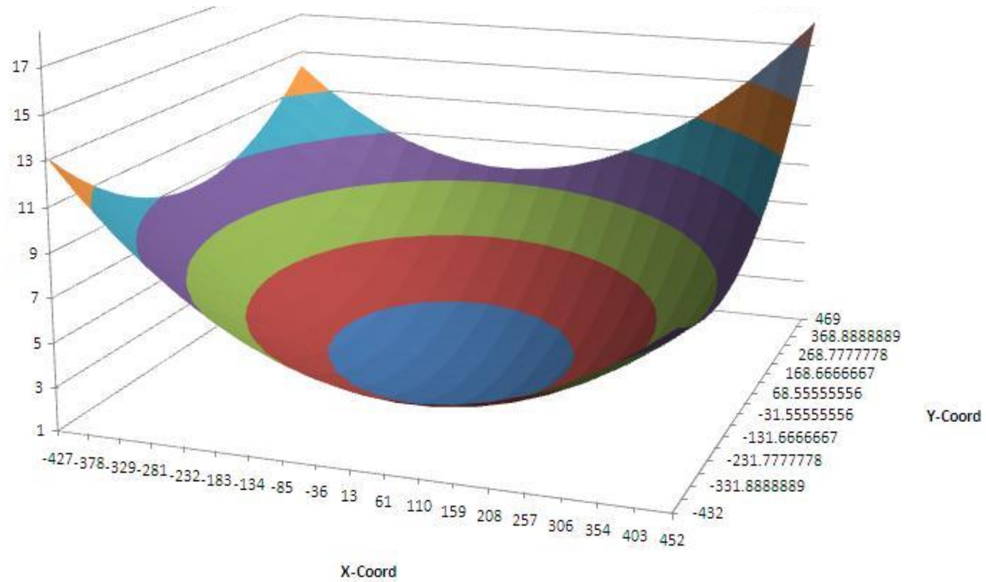


Figure 2: Surface plot of absolute fall-of-shot error (mm) on vertical axis versus target location in X and Y coordinates (mm) at base (Sisson & Joiner, 2018)

**Electronic Warfare.** Two electronic warfare testing officers doing the revised subject screened a simulated threat system using HTT techniques for an efficient and exploratory test plan. While the testing focused quickly on an expected weakness of the threat system, two other areas of new interest were observed. Such operational discovery is an important part of this unit's support to fielded systems. This early success led several subsequent students to be permitted to use HTT techniques on other aircraft survivability testing (Grafton et al., 2018). The techniques were highly efficient, but in two instances the usual rigour of good modelling of significant factors appeared to be obscure. Mentoring was key to identifying that the binary output of '*decoy*' or '*no decoy*' was failing in linear regression to produce a valid model and that instead the untaught skill of logistic regression was needed. Such phenomenon in data analytics has been noted (Kiemele, 2017) and is covered in applied theory (Hosmer, Lemeshow & Sturdivant, 2013). Declassified surface plots of the linear and logistics regressions of this test data are shown for contrast (Figure Three).

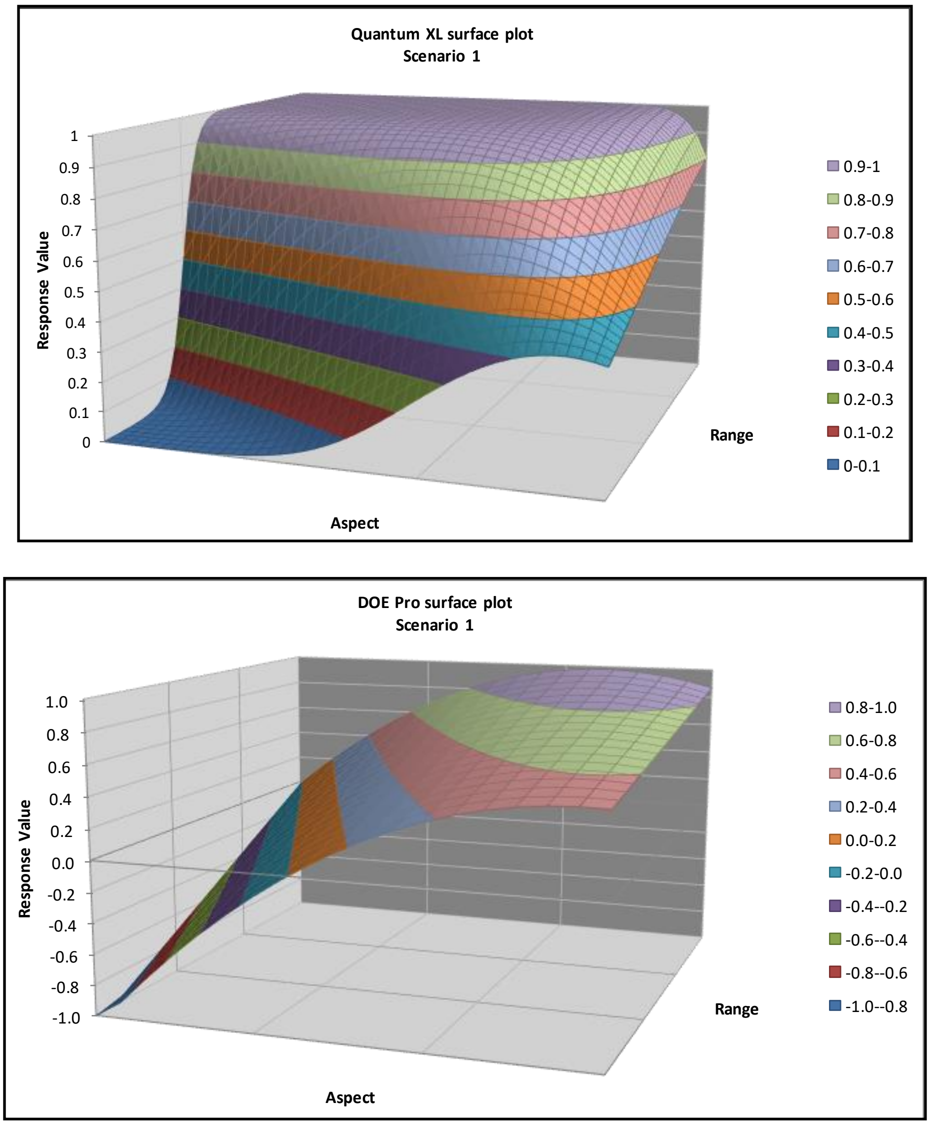


Figure 10: Comparison of the same aircraft survivability test data analysis from linear regression and logistics regression (Grafton et al., 2018)

The electronic warfare unit is educating some green-belt mentors who can assist the analysis of such binary problems encountered commonly in the construct of electronic warfare and cybersecurity testing.

**Ship.** The third test unit to invest heavily in SS techniques in 2017 operationally tests new ships. Understandably in the time available students have not used the techniques on whole-ship testing, however, they were able to analyse prior data (Wernas & Joiner, 2018). Early operational testing of new ships includes a focus on supportability, in particular if the ship's crew can perform planned maintenance from the delivered ship schedules and maintenance training. The test data analysed came from a large new ship, was qualitative and was based on 29 involved questions applied over a hundred times in different ship maintenance tests. The SS analysis proved very effective in screening which of the supportability assessment questions and their key interactions had the greaest effect on the overall assessment of ship suitability. Two questions in particular, with their associated interactions, accounted for half of the overall effect. Figure Four shows just one of the key interactions. This work is expected to be influential in focusing the supportability assessments for the new Hobart class ships.

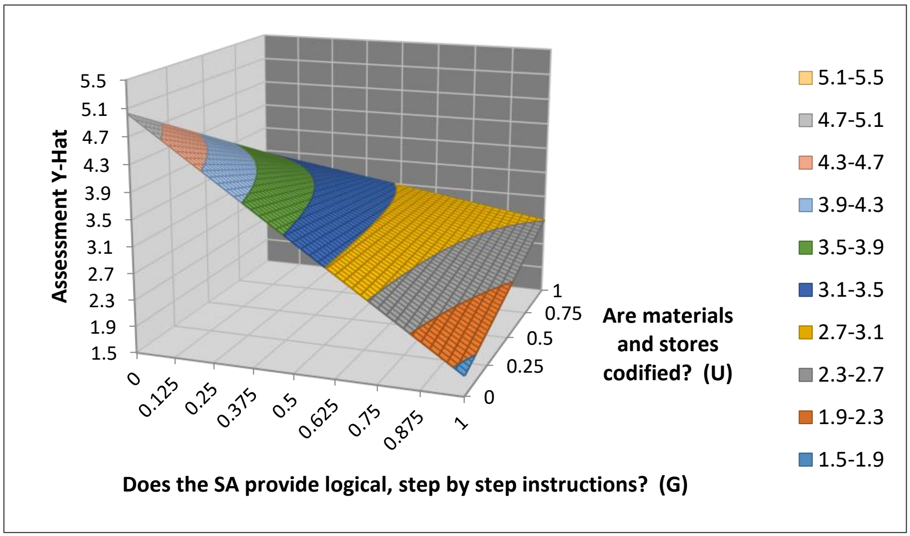


**Figure 4: Example interaction from Ship Supportability Test Analysis**

## Future Directions

The case studies have also guided several further subject improvements. First, the subject will use the more capable Quantum XLTM vice the introductory DOE PRO XLTM. 1 Defence students are usually very capable and their units struggle with a myriad of software applications, so it is hoped the change proves suitable for use from the introductory stage. The course will also highlight the critical role of SS techniques in screening software testing and cybersecurity (Christensen, 2015; Joiner & Rehman, 2017), especially the use of combinatorial rigour up to six-way combinations (Kuhn et al., 2016; Kuhn, Kacker & Lei, 2010) as exemplified by industry awards like Mackertich et al. (2017). The free-ware combinatorial package known as Automated Combinatorial Testing for Software (ACTS) is suitable for illustrating such test design as an extension to the two-way combinatorial package used now. 2 An example test coverage chart from ACTS at three-way rigour and the associated factor table are shown in Figure Five and Table One respectively. This example is used in a lecture into how to screen the common weakness enumerators (CWE) of an computer architecture for cyber-vulnerabilities.

| Factors | Levels |
|---|---|
| Application | [Active, Not_Active] |
| Hardware | [Type_1, Type_2] |
| Obscuration | [Low, Moderate, High] |
| Attack_Frequency | [Rarely, Sometimes, Often] |
| Weakness_Prevalence | [Rarely, Sometimes, Often] |
| CWE_Category | [Type_1, Type_2, Type_3, Type_4, Type_5] |

[1] Quantum XL™ and DOE PRO XL™ are copyright Air Academy Associates, LLC, and SigmaZone.com.
[2] rdExpert (lite)™ , copyright Phadke Associates, LLC.

**Table 1: Factor table in cybersecurity combinatorial test illustration**

The test coverage feature of ACTS is excellent for showing the value-ordering of combinatorial tests. However, the lesson on how important an improved orthogonality option can be to combinatorial tests is still necessarily taught in a licensed package with that feature.

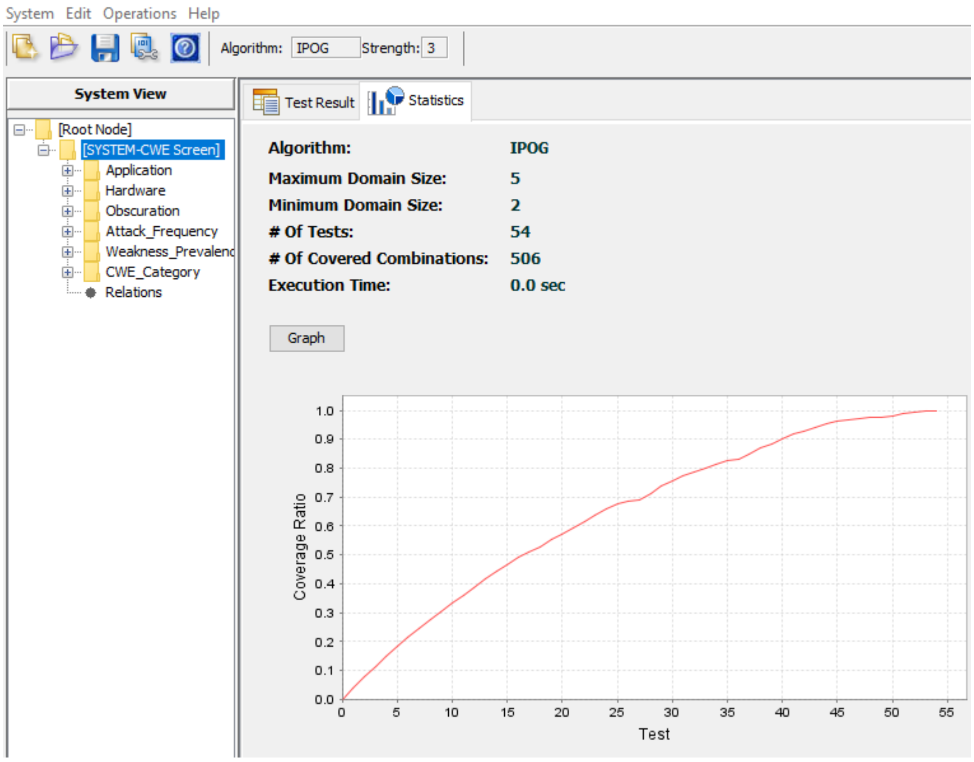


**Figure 5: Test coverage at a rigour of three-way combinatorial using free-ware ACTS package**

In order to help students with SS reform the subject will include a new textbook with coverage of SS cultural issues especially in service industries (Antony, 2014), which the author found were symptomatic of defence use. Finally, the subject will change the system students collaboratively explore in the intensive week from that of the catapult, featured in Joiner and Brewster (2017), to the more contemporary challenge of a line-following robot (Figure Six). This robot is more exemplary of challenges in defence testing concerning software-driven functionality and autonomy (i.e., Hanly & Joiner, 2018).

**Figure 6: 3pi line-following vehicle and robot system being developed as test teaching system[3]**

In terms of penetrating SS testing in Defence, future work is on building more case studies, seeking a recommendation in tri-service test policy and meeting the dearth of qualified cybersecurity test professionals needed in Australia for that growing threat axis (Lewis, 2017; Henry, 2017; Joiner, 2017).

## Conclusion

In 2010, U.S. Defense introduced mandatory use of SS testing in its T&E, including a comprehensive education and support structure. Australian Defence quickly offered these courses to its T&E staff for three years without achieving usage. However, a new educational and reform approach in the last two years has seen the SS techniques used in several Defence test organisations with benefits in test rigour and efficiency.

This longitudinal review of SS reform in Australian Defence testing covers six years and outlines the lessons learned in penetrating SS use. Test policy, properly leveraged and powerful as it is in the U.S. Defense, is a powerful change agent that Australian Defence could not easily mimic. Instead, a bottom-up reform was necessary, where it was crucial that necessary test staff were targetted for attendance and that the education included hands-on competence in the classroom, mentored use and assessment back in the workplace, and case study presentation for management. These lessons are of benefit to any beaucratic organisation hoping to leverage SS testing.

Educators of SS need to consider the in-work mentoring and assessment pedagogy as critical wherever SS has no extant foothold. Ideally these educators should be employed with long-term partnering on implementation and culture, rather than simply student numbers. Future SS subject improvements were outlined, focused on tailoring the subject to meet the challenges of cybersecurity testing and autonomous systems, as well as to better prepare students for real-world initial test assignments by facilitating more mentors, better texts and enhanced software support.

## References

Ahner, D. K., 2016. ‘Better buying power, developmental testing, and scientific test and analysis techniques,’ *ITEA Journal*, 37, pp. 286-290.

Antony, J., 2014. *Design of Experiments for Engineers and Scientists*, London: Elsevier Ltd.

Brooks, M. & Joiner, K. F., 2017. Small Arms Terminal Effects: Implementation of a DOE methodology in order to design small arms terminal effects tests, *PARARI 2017*

[3] 3pi system sold by Pololu & featured at https://www.robotgear.com.au/Product.aspx/Details/326-Pololu-3pi-Robot-Kit and https://youtu.be/RVBYWHOarRE .

- *Australian Explosive Ordnance Safety Symposium*, UNSW Canberra, 21 - 23 November.

Christensen, P., 2015. *Introduction to Cyberspace T&E*, tutorial at 32nd Annual International Test and Evaluation Symposium, 18-21 August, Director, National Cyber Range.

Chu, D. S. C., 2016. Statistics in Defense: A guardian at the gate, *ITEA Journal*, 37, pp. 284-285.

Defense Acquisition University (DAU), 2015. *DAU T&E Workforce Development Process*. DAU presentation by Professor Frank Kenlon, Mr Ed Verchot & Dr Paul Alfieri to Group Captain (Dr) K. Joiner of Australian Defence T&E Office and University of NSW, 17 August 2015.

Grafton, R.; Brown, G.; Novakovic, Z. & Joiner, K.F., 2018 (submitted). Developments in test design and analysis techniques for aircraft survivability assessments, *Systems Engineering, Test and Evaluation Conference*, Sydney, Australia, 30 April - 02 May 2018

Hanly, G. & Joiner, K. F., 2018 (submitted). Test and Evaluation of Factors affecting Facial Recognition Performance of Systems, *Systems Engineering, Test and Evaluation Conference*, Sydney, Australia, 30 April - 02 May 2018.

Henry, A. P., 2017. *Mastering the Cyber Security Skills Crisis: Realigning Educational Outcomes to Industry Requirements*, discussion paper at University of New South Wales, http://dx.doi.orghttps://www.unsw.adfa.edu.au/australian-centre-for-cyber-security/sites/accs/files/uploads/ACCS-Discussion-Paper-4-Web.pdf .

Henry, R. & Joiner, K. F., 2017, Improving Small Arms Ammunition Qualification with Statistical Test Techniques from U.S. Defense, *PARARI 2017 - Australian Explosive Ordnance Safety Symposium*, UNSW Canberra, 21 - 23 November.

Hosmer, D. W.; Lemeshow, S.; & Sturdivant, R. X., 2013. *Applied Logistic Regression*, John Wiley & Sons, Incorporated, 2013. ProQuest Ebook Central.

Johnson, R. T., Hutto, G. T., Simpson, J. R., & Montgomery, D. C., 2012. Designed experiments for the Defense community. *Quality Engineering*, 60-79.

Joiner, K. F., 2017. How Australia can catch up to U.S. cyber resilience by understanding that cyber survivability test and evaluation drives defense investment, *Information Security Journal*, vol. 26, pp. 74 - 84, http://dx.doi.org/10.1080/19393555.2017.1293198 .

Joiner, K. F. & Brewster, A. L., 2017. Cooking perfect cupcakes: Freeing curricula context gives student-centred pedagogy for course on experimental design, *Creative Education*, vol. 8, pp. 1833 - 1859, http://dx.doi.org/10.4236/ce.2017.812126.

Joiner, K. F. & Rehman, O., 2017. Test Strategy to detect Industrial Control Systems' common Cyber Weaknesses and Vulnerabilities, *Proceedings 27th Annual INCOSE International Symposium* (IS 2017), Adelaide, Australia, July 15-20.

Joiner, K. F. & Tutty, M. G., 2018. A tale of two Allied Defence Departments: New assurance initiatives for managing increasing system complexity, interconnectedness, and vulnerability, *Australian Journal of Multidisciplinary Engineering*, http://dx.doi.org/10.1080/14488388.2018.1426407.

Joiner, K. F.; Kiemele, M.; & McAuliffe, M., 2016. Australia's First Official Use of Design of Experiments in T&E: User Trials to Select Rifle Enhancements, *ITEA Journal*; 37, pp. 141-152.

Joiner, K. F.; Zahra, J. & Rehman, O., 2018 (submitted). Conceptual Sizing of Next Supersonic Passenger Aircraft, *2018 Asia Conference on Mechanical Engineering and Aerospace Engineering*, Wuhan, China, 23 - 25 June.

Kass, R. A. 2015. Twenty-one parameters for rigorous, robust and realistic operational testing, *ITEA Journal*, 36, pp. 121-138.

Kiemele, M., 2017. Data Science and its Relationship to Test & Evaluation, *ITEA Annual Symposium,* Technical Track Reston, VA October 3.

Kuhn, D. R.; Kacker, R. N.; & Lei, Y., 2010. Practical Combinatorial Testing, *National Institute of Standards and Technology (NIST) Special Publication (SP)* 800-142, October, 82 pp., available at http://dx.doi.org/10.6028/NIST.SP.800-142 .

Kuhn, D. R.; Kacker, R. N.; Feldman, L.; & White, G., 2016. Combinatorial Testing for Cybersecurity and Reliability, *Information Technology Bulletin for May 2016*, Computer Security Division, Information Technology Laboratory, National Institute of Standards and Technology, U.S. Department of Commerce, available at https://www.nist.gov/publications/combinatorial-testing-cybersecurity-and-reliability .

Lednicky, E. J., & Silvestrini, R. T. (2013). Quantifying Gains Using the Capability-Based Test and Evaluation Method. *Quality Reliability Engineering International*, pp. 139-156.

Lewis, D., 2017. Cybersecurity skills shortage putting public, private sectors at risk, experts say, Australian Broadcasting Corporation news article, 13 June, available at http://www.abc.net.au/news/2017-06-09/cybersecurity-skills-shortage-putting-australia-at-risk-expert/8601426 .

Mackertich, N.; Kraus, P.; Mittlestaedt, K.; Foley, B.; Bardsley, D.; Grimes, K.; & Nolan, M., 2017. *IEEE/SEI Software Process Achievement Award 2016 Technical Report*, Raytheon Integrated Defense Systems, Design for Six Sigma Team, March.

Murphy, T., L. D. Leiby, K. Glaeser, and L. Freeman. 2015. How Scientific Test and Analysis Techniques Can Assist the Chief Developmental Tester, *ITEA Journal*, 36: pp. 96–101.

National Institute of Standards and Technology (NIST), 2018. *Process Improvement Handbook* http://www.itl.nist.gov/div898/handbook/pri/pri.htm, accessed January.

Pulakanam, V., 2012. Costs and savings of Six Sigma Programs: An empirical study, *The Quality Management Journal*, 19(4), pp. 39-54.

Reagan, L. A., & Kiemele, M. J., 2008. *Design for Six Sigma: The Tool Guide for Practitioners.* Colorado Springs: Air Academy Associates, LLC.

Rucker, A. 2014. Improving statistical rigor in Defense T&E: Use of tolerance intervals in designed experiments, *Defense ARJ*, 21(4), pp. 804-824.

Schmidt, S. R., & Launsby, R. G., 2005. *Understanding Industrial Designed Experiments*. Colorado: Air Academy Associates.

Simpson, J. R.; Listak, C.M.; & Hutto, G. T., 2013. Guidelines for Planning and Evidence for Assessing a Well-Designed Experiment, *Quality Engineering*, 25:4, pp. 333-355, DOI: 10.1080/08982112.2013.803574

Sisson, G. & Joiner, K. F., 2018 (submitted). Applying new analysis techniques to calibrate use of a projectile locating system in ammunition testing, *Systems Engineering, Test and Evaluation Conference*, Sydney, Australia, 30 April - 02 May 2018.

U.S. Department of Defense (DoD), 2010. *Guidance on the use of Design Of Experiments (DOE) in Operational Test and Evaluation (OT&E)*, Office of Secretary of Defense, Director of OT&E, Memorandum 19 October.

U.S. DoD, 2014. *Director Operational Test and Evaluation (DOT&E) 2014 Annual Report to Congress*, Office of Secretary of Defense, [read section on rigorous, defensible, efficient testing].

U.S. DoD, 2018. STAT Centre of Excellence. https://www.afit.edu/STAT/ , United States Air Force Institute, accessed 19 February.

Wernas, M. & Joiner, K. F., 2018 (submitted). Screening the important factors in Supportability Test and Evaluation activities for Ships', *Systems Engineering, Test and Evaluation Conference*, Sydney, Australia, 30 April - 02 May 2018

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Dr Keith Joiner, CSC, joined the Air Force in 1985 and became an aeronautical engineer, project manager and teacher over a 30-year career before joining the University of New South Wales in 2015 as a senior lecturer in test and evaluation. In 2009, he was awarded a U.S. Meritorious Service Medal for serving with multinational forces in Baghdad developing force drawdown plans and the repatriation of bases within Iraq. From 2010 to 2014 he was the Director-General of Test and Evaluation for the Australian Defence Force, where he conducted numerous joint test and evaluation and where he was awarded a Conspicuous Service Cross. He is a Certified Practising Engineer and a Certified Practising Project Director.