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Comprehensive Study on Mobile Security Risks and Biometrics Techniques

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Abstract: As the technology is on the horizon, digital data such as media, private documents and personal social media profiles became valuable just as much as physical items. As our heavy reliance of electronics increases, protecting them from unauthorized access becomes even more important since people are storing very sensitive information in their mobile devices. Mobile security has been debatable for a long time now in terms of what to add, what to take off, or how to deal with it properly. In addition, the more the technology advances the harder it is to keep up with the security. So, mobile security has advantages and drawbacks. This paper will discuss mobile security, risks and biometrics and the limitations of technologies.

Keywords: Mobile Security, Wireless Security, Security Threats, Biometrics, Security Requirements.

1 INTRODUCTION

Nowadays smartphones are in the hands of almost every person on earth and our reliance on them is increasing more as days pass by. In fact, The International Telecommunication Union estimates that 95.5% of the world has a mobile subscription plan which is around 7 billion of the earth population [3]. People use their smartphones for many purposes such as entertainment, media, business, banking and many sensitive information so making the phone is protected is more important than ever. Thankfully, smartphone manufacturers are investing heaving in the research and development of biometrics and how they can be applied as a form of security in smart devices.

Within the last 10 years or so, mobile devices have become powerful and fast enough to be considered an essential part of our everyday lives, as they contain applications and the ability to do almost anything we want. For example, they are used to store contact information such as numbers and emails, they also store all types of passwords that you use for almost everything in your daily life, and bank information is also typically stored on your mobile device. They are also essential for very sensitive highly classified data in government such as military or high-level government scenarios, which is why the integrity and the security of mobile phones have to be treated with the utmost importance nowadays since they contain so much critical and sensitive information. For more than a decade presently, IT frameworks with progressed security prerequisites apply problem-specific security arrangements for indicating, analyzing, and upholding key security concepts, and standards have risen that are able of implementing security approaches specifically by the operating systems.

Given the important significance of policy correctness in such systems, policy engineering based on formal strategies and formal security models have been set up that permit a verified specification and usage of security components and models. Different operational conditions (distributed systems including mobile components) and different applications (e.g. considering environmental conditions such as geographical location) result in additional threats and vulnerabilities. Mobile devices are generally not physically protected and can be stolen easily; they command a multitude and diversity of communication alternatives using untrusted or even hostile communication infrastructures. Communication is often spontaneous, volatile, and unpredictable, and communicating parties frequently are only weakly authenticated or just hostile.

As stated above, mobile security is vulnerable in many ways and the fact that mobile devices have become such an integral part of everybody’s everyday lives means security has become exponentially harder to contain since mobiles are used for almost everything which includes calling, sending text messages, using social media, checking emails, storing critical and confidential information on the mobile itself and the cloud based services that can be accessed from it. This means that any compromise in the security of the mobile can expose its owner to danger such as leaking essential confidential information, passwords being stolen and threats & blackmail [15].

In this paper, multiple angles and aspects of mobile security will be discussed such as what mobiles are currently used for, what power they have and thus how the security should be maintained in order not to be breached. Multiple examples and cases will also be discussed to give a clear state of current mobile security.

2 RISK ASSESSMENTS

2.1 Security Requirements

The following risk assessments can be used to properly identify any risks or resources that can be compromised within a system, and any security hole that is exploited is usually, in most cases one or a combination of these risks combined. They also detail that should be executed on all levels of mobile security [11][14][16][22][23][19][18][17].

- Weak Server-Side Controls. Auditor should ask application owner for access to the web server and check for mirrored authentication and input validation.
- Insecure Data Storage. Auditor should check for locations of where data is stored by the application and ensure adequate protection is in place.
- Insufficient Transport Layer Protection. Auditor should perform packet capturing to ensure adequate cipher suites are used for data in transit. Auditor should also check for endpoint verification before transmission of sensitive data.
- Unintended data leakage. Auditor should investigate all locations that the application writes to.
- Poor Authorization and Authentication. Auditor should check to make sure that forced online authentication is in place. If there is offline authentication, then credentials should be encrypted.
- Broken Cryptography. Auditor should check to make sure that encryption keys are of adequate size and stored securely. Also, poor encryption algorithms not be used.
- Client-Side Injection. Auditor should check for adequate input validation such as parameterized queries. Web View component should be checked for secure use.
- Security Decisions via Untrusted Inputs. Auditor should check for messages to be input validated.
- Improper Session Handling. Auditor should check to make sure application session is terminated in a timely manner. Auditor should also be checking for proper session cookie handling.
- Lack of Binary Protections. Auditor should check to make sure application session is terminated in a timely manner and check for deliberate code obfuscation.

2.2 Factors

- Permissions. Applications request permissions for the application to access the device location, storage and contacts. It always going to ask from you for your permission so if a hacker hacks through an application then he/she going to be stuck on permissions.
- Sandboxing. Phones use sandboxing technique. As it is called it’s like a sandbox that doesn’t let any sand out or any sand in. Thus, applications in mobile phones has their own data so no data comes in from another application. If any data were to be sent from another application or received it needs a permission first in order to do so. Hackers won't be able to get any information from another apps without permission even if they manage to hack an application.
- Source of credited software. The source of software is limited. It’s most likely either the app store or play store. Plus, developers must be checked and registered before they can upload their applications. Since it is limited it is less likely to have malicious code imbedded inside the data it provides. So, it has lower risk of installing harmful code.
- Cellular network is safer then public Wi-Fi. The phone receive connection from the company the same way it receives the serves to make a phone call. And what is good about is that it is encrypted. That means it is hard to be hacked and by getting VPN out of the equation cellular network is the hardest one to be hacked then comes Wi-Fi.
- IP address. It is useless to obtain a phone IP address for phones that are using cellular network. Of course a hacker uses an IP address to hack someone’s computer or device but what if it is continuously changing. Mobile IP address keep on changing because it doesn’t have stationed location like computers, but it communicates with the nearest cell tower which causes the IP to change.
- End to end Encryption. Some of the applications use this technique like WhatsApp Company have decided to make every message including calls, voices and videos encrypted. Even the company itself can't see these massages. No man in the middle would be able to hack though this and because it is not impossible because nothing is secure one hundred percent it is a very hard task. That would increase security of communicating important information if needed.

3 BIOMETRICS

3.1 Biometrics Field

The Field of biometrics and their application in electronics really expanded and started developing rapidly between the 1970s and the 2000s. This this period, Fingerprints became mandated by many institutions and development on face recognition, iris scanners, speaker's recognition, hand identification and many other biometrics we use today. However, back then most of those technologies were still in their infancy since many of them were still being researched, developed and tested [2][3][5][7][11][10].

3.2 Biometrics Types

Arguably the most popular biometric being used in smart devices is the Fingerprints.

Figure 1. Fingerprint

The fingers are scanned with a captive scanner where electric currents are being sent to the finger once it touches the scanner. The captive scanner will measure the air gaps between the ridges and maps the contact points as a unique identifier. Captive scanners are what is being used in most smart devices and laptops. Thankfully, the data of the fingerprints are stored in the device itself not in an external server. In some cases, like in apple touch ID, an algorithm is used to generate a numeric representation that is stored in the server but even then, the data of the mathematical equivalent is still encrypted so data breach that target the fingerprints information is extremely unlikely. Android phones work in a similar fashion to the method used in Apple devices where the data of the fingerprints are encrypted and stored in a part of the CPU called the "Trusted Execution Environment" which is designed in a way that would not interfere with other installed applications nor give the applications the ability to access them directly [4]. Outside of Smartphones, fingerprints scanners are being used in vaults, offices doors and many other personal documents such as passports and Identification cards. Iris scanning is also a biometric that is new to the field which even though works well by todays standards, it still is a developing technique.

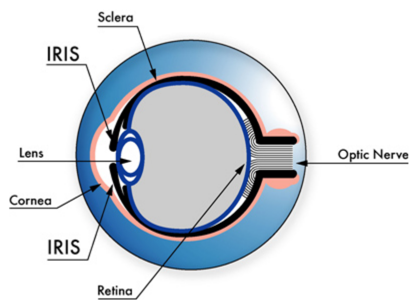

Figure 2. Eye Parts.

The iris is the colored open circle of tissues surrounding the pupil. The combination of the iris shape and color is very complex which gives person a unique attribute when it comes to the eyes. Iris scanners take advantage of the fact that everyone has a unique eye and applies it as a form of security. The scanners use infrared rays to scan the eyes and gather the needed information for authentication. However, in the case of smartphones, they use both the camera and infrared scanners for low light conditions which identifies over 200 features of the eyes [5].

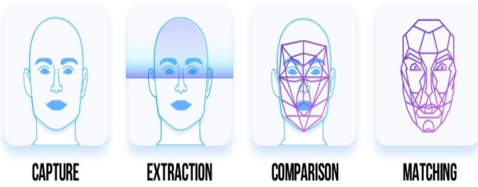

Figure 3. Facial recognition

Facial Recognition as a form of biometric has been around for a long time however, due to the details it needs to capture, it hasn't been widely used. But with cameras improving very quickly and being able to capture more and more details, facial recognition became easier to achieve. Face recognition works by analyzing the facial structure of the person and mapping it to a mathematical algorithm. Some smartphones that integrate the facial recognition biometric compare around 30,000 features of the face to minimize the ability to spoof the software with a picture or a 3d modeled figure of the person face.

Facial recognition is also used in home entertainment such as the Xbox Kinect where the camera can differentiate between the players according to their face. In addition to that, it is widely used in Facebook for tagging purposes in pictures. The way it works is that every time a user is tagged in a picture, the server stores some facial features about that tagged person. The more they are tagged the easier they can be identified by the software. The users can still disable this feature for security purposes [6]. In the United States, some airports use Facial Recognition technology for travelling passengers as a form of security. Unfortunately, there are still security concerns associated with this technology. Some people have doubts whether the data of the face are truly stored in the phone or are they secretly being stored online in a database. Some theorists are also suggesting that the face data are being used for law enforcement agencies without the civilian knowledge or permission. In store cameras can also be used to detect our faces and match it with other databases to find the identity of the shopper. It can be used as a form of advertisement to the user depending on what they were shopping for that day or what the cameras detected that they were mostly looking at. Cameras are now so advanced and use many complex algorithms to differentiate between different people and different objects however, whether that is used for malicious purposes or not is still up to debate [7].

Another form is biometric that is rarely used for security purposes is Speaker recognition. There are two forms of speaker recognition. One called text dependent which relies on what the subject is saying, which can used as a phrase for access. For example, the system a request from the user to say a specific string of words. The second type called text independent where the user can just use their voice to verify their identity. There are four steps when it comes to identifying a person's voice. First is voice recording where it takes into account the individual's pitch, voice frequency, speed and any other attributes related to the voice.

The second step is feature extraction where the recorded voice is divided into small frames. Then, pattern matching is where the voice is compared with other saved voice templates. In this phase, an algorithm is also used to differentiate the person from other speakers that previously used the system. Finally, the decision step is next which happens when the previous steps have already been processed to authenticate the user that is trying to use the speaker recognition biometric. Voice recognition is heavily used in call centers especially with banks or companies that deal with sensitive information. The voice of the customer can be used as a biometric to verify their identity in case of a doubt. In some cases, it is also used with the combination of facial recognition as a two layered security measure [8].

4 SECURE DATA TRANSMISSION

One exceptionally noticeable illustration is the TLS protocol (Transport Layer Protocol), a successor of the initial SSL protocol. TLS is as of now one of the foremost well-known security conventions and is acknowledged as a secure way for undisclosed communication. Nevertheless, [24][25] TLS can only ensure that the communication to the end-point is protected and cannot guarantee the protection of the protocols that are underlying beneath this communication e.g. execute the verification of clients with services. Even if the system or service has a working encryption protecting and securing it, any design or implementation errors that affect these mechanisms or protocols can be exploited and used to cause harm or whatever it is that the exploiter intends to achieve with the attack. Moreover, another principal issue is regularly ignored: The sole purpose of TLS is to protect and secure the communication when two reliable end-points are communication, i.e. both parties know and trust each other. In mobile applications, this would pre-requisite would not be applicable most of the time as you always have to consider the consumer as a potential hacker and thus can't always secure the communication since the consumer's motivation and actions are unknown to you.

Developers often rely on the assumption that they possess full control over their mobile application, so they also assume that it is perfectly safe for the application to connect and contact with clients over the Internet because they are under the assumption that they can control the whole network of communication. Even though the transport layer is protected by encryption such as TLS or the older SSL, it is still possible to be exploited if the developers do not amend their approach and modify it to be able to secure all means of communication as much as possible. Furthermore, this additional encryption layer adds even more complexity to the testing phase and sometimes even prohibits extensive security testing.

To illustrate some test cases to highlight the results of the testing shortcomings that can be found by utilizing the procedure proposed above by giving real life examples. The applications were chosen based on the user base of the examples and how many fields it can generally cover.

4.1 Mobile Instant Messengers:

These types of applications have been widely spread and come in many different forms, which means they have been analyzed quite frequently over the past years. Most of the application's security relies quite heavily on two-factor authentication, either through phone number or email or a randomly generated code every set number of seconds/minutes, but they are still using TLS at the same time. Even with these security measures, they still contain security flaws which can be exploited. An example can be seen here (authentication mechanism in WhatsApp):

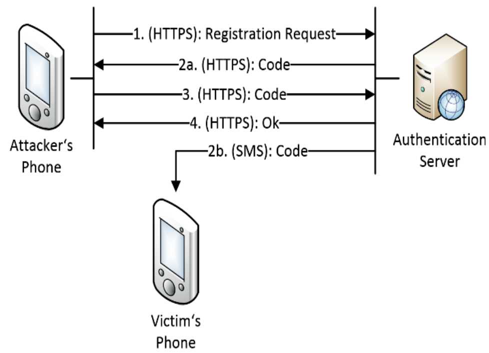

Figure 4. WhatsApp communications.

The user (legit or fraud) enters a request for authentication in the app which triggers the sending of a SMS to this number containing a short code which needs to be entered in the app to verify the possession of the claimed number.

4.2 Games and Entertainment:

Mobile games have become a major source of entertainment and many of the top charts for leading mobile applications consist of online or offline games. Most of the games have some form of micro-transactions as in app-purchases which users use to buy special items in game or gain special features. For example the well-known game 'Guild Wars II' was chosen, where you are a character and have to fight monsters to advance in the game using armor and weapons. The user could gain a significant advantage if they buy the 'weapons and armor' and bonuses. These in-app purchases are set by the user and thus they could be abused.

4.3 Social Media:

Snapchat is a social media class leading app that allows you to send photos to users which may or may not be your friends and them sending you photos back. You can also reply with text and start conversations with users across photos, videos and text. The issue with this is that the photos are temporarily stored on your device in file names that are constructed via a pattern, so as soon you as are able to exploit the TLS layer and bypass it, you have access to all the user's photos in this application and can make them available to download, a feature that Snapchat does not allow.

4.4 Online Shops:

Applications which rely on the user buying items from online shops such as clothes, items, tickets or anything that is similar are also prone to these kind of attacks, which can be avoided by using a proper testing strategy.

Next, operating system vulnerabilities will be discussed to find out how some OS's are specifically targeted, and bugs exploited, mainly with Apple, Microsoft, and Google. Each smartphone operating system (OS) has security vulnerabilities that are unique to its system. Security vulnerabilities are also unique to the mobile's specific operating system (OS). For example, Apple's system of pushing out updates is very similar to Microsoft's in which they release security updates using their operating systems. That means that they target their OS and release updates for the entirety of the OS across all their devices. On the other hand, Android works in a different way.

Google for example, can only push out updates for Google made devices which use Android, while Samsung can only push out updates for Samsung made devices even though they both use the Android operating system. Research shows that Android's latest OS updates penetrate the Android devices much slower than Apple or Microsoft and as a little as 0.7% of mobiles that have Android as their operating system have the latest security updates. This effects the Android user base very hard as mobiles using Android quickly lose security update and support and thus become much more vulnerable to attacks.

5 FUTURE OF BIOMETRICS

Developers and Engineers barely scratched the surface when it comes to advancements and fully using biometrics to its full potential.

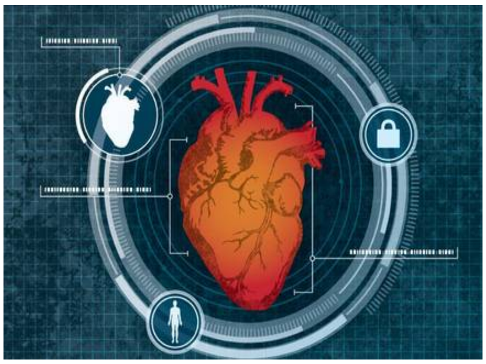

Figure 5. Blood flow biometric.

For example, Researchers have found out that blood flow in each body is unique which makes it a potential contender as a biometric. Many patents have been found whether the scan will take place from the palms or any other area of the body where blood flow can be sensed. Some current biometrics may be expanded into even more areas [26].

For example, some cars allow the use of fingerprints as a biometric, but engineers are experimenting with using facial and iris recognitions as well [27]. Another future form of biometric may even exist with the way we use our keyboard. The way it works is that the keyboard will take into account the speed of the typing and pressure applied to each keystroke which when calculated with very small and precise numbers they will most likely be unique to each person. Another thing to add is the fact even if someone knows your password they still will not be able to bypass the biometric that is within the keyboard itself that is expecting your style of typing [28]. Finally, Movement based biometrics may be implemented in the future as well. The way it works is that a camera will track the body skeletal movement and identify the person based on it. It will most likely be used in home securities where only the authorized people of the house can enter. It also be used in office or companies especially when handling sensitive rooms such as the CEO office [27].

6 CONCLUSION

In conclusion to mobile security requirements, mobile devices in general are quite secure but can at the same time be exploited using a single bug, which can lead to leaking of a lot of sensitive information, or access to kernel privileges through rooting with Android phones or jailbreaking with Apple devices which gives the exploiter full access over the device which obviously puts the users at risk.

Biometrics never had an easy start it was always a complex form of identification ever since it was popularized with the Bertillon method where measurements of the human body and attributes were scanned nondigitally biometrics each method has its own advantages and disadvantages whether its cost or security. Biometrics is also not foolproof since people have been able to forge fingerprints and irises with the use of pictures alone gathered from the internet. The future of biometrics looks promising with more research and development being put in the field to make sure we live a private safe life in this age where electronics that contain our data are everywhere.

REFERENCES

[1] Pike, John. "Biometrics - History." Homeland Security. N.p., July-Aug. 2009. Web. 15 May 2018.
[2] Mayhew, Stephen. "History of Biometrics." BiometricUpdate. BiometricUpdate.com, 21 Mar. 2018. Web. 15 May 2018.
[3] Hassan, Mehedi, John Trader, and Masum Shibli. "How Biometrics on Smartphones Is Changing Our Lives." M2SYS Blog On Biometric Technology. M2SYS Blog On Biometric Technology, 13 July 2017. Web. 15 May 2018.
[4] DASCALESCU, ANA. "Biometric Authentication Overview, Advantages & Disadvantages."Heimdal Security Blog. HeimdalSecurity, 30 Jan. 2018. Web. 15 May 2018.
[5] Pilcher, Pat. "How Iris Scanners on Smartphones Work." Stuff. N.p., 15 Aug. 2016. Web. 15 May 2018.
[6] Rouse, Margaret. "What Is Facial Recognition? - Definition from WhatIs.com."SearchEnterpriseAI. Whatls, 5 Jan. 2018. Web. 15 May 2018.
[7] Wall, Matthew. "Is Facial Recognition Tech Really a Threat to Privacy?" BBC News. BBC, 19 June 2015. Web. 15 May 2018.
[8] Admin. "Speaker Recognition." Biometrics. N.p., 2016. Web. 15 May 2018.
[9] M. Harbach, A. De Luca, and S. Egelman. The anatomy of smartphone unlocking: A field study of android lock screens. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pages 4806–4817. ACM, 2016.
[10] Khosrow-P, Mehdi. Contemporary Advancements in Information Technology Development in Dynamic, IGL Global publishers, 2014.
[11] Ganorkar, Sanjay R, and Ashok A Ghatol. “Iris Recognition: An Emerging Biometric Technology.” pp. 91–96., www.wseas.us/e-library/conferences/2007corfu/papers/540-292.pdf. Accessed 4 Nov. 2017.
[12] Plamen. “Samsung Galaxy S8's Iris Scanner Could Be Used for Mobile Payments.” Phone Arena, 21 Apr. 2017, www.phonearena.com/news/Samsung-Galaxy-S8s-iris-scanner-could-be-used-for-mobile-payments_id93300. Accessed 25 Apr. 2017.
[13] Titcomb, James. “Why Your Smartphone's Fingerprint Scanner Isn't as Secure as You Might Rhink.” The Telegraph, Telegraph Media Group, 11 Apr. 2017, www.telegraph.co.uk/technology/2017/04/11/smartphone-fingerprint-scanners-could-easily-fooled-fake-prints/. Accessed 23 Apr. 2017.
[14] M. Pavloski, "A Performance Approach to Mobile Security," 2016 IEEE 24th International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS), London, United Kingdom, 2016, pp. 325-330.
[15] P. Amthor and W. E. Kuhnhauser, "Security Policy Synthesis in Mobile Systems," 2015 IEEE World Congress on Services (SERVICES), New York City, NY, USA, 2015, pp. 189-197.
[16] D. Yang and I. Hwang, "Security Enhancement Methods for Mobile POS System," 2015 2nd ACM International Conference on Mobile Software Engineering and Systems (MOBILESoft)(MOBILESOFT), Florence, Italy, 2015, pp. 152-153.
[17] G. Thamilarasu and C. Lakin, "A Security Framework for Mobile Health Applications," 2017 5th International Conference on Future Internet of Things and Cloud Workshops (FiCloudW), Prague, Czech Republic, 2017, pp. 221-226.
[18] Bilić, D. and Bilić, D. (2018). Mobile devices can be safer and more secure than you might think. [online] WeLiveSecurity. Available at: https://www.welivesecurity.com/2018/01/19/mobile-devices-insecure-nature/ [Accessed 15 May 2018].
[19] Cooney, M., World, N. and World, N. (2018). 10 common mobile security problems to attack. [online] PCWorld. Available at: https://www.pcworld.com/article/2010278/10-common-mobile-security-problems-to-attack.html [Accessed 15 May 2018].
[20] Shibli, Masum, John Trader, and Mehedi Hassan. "Nissan Concept Car Features Fingerprint Identification." M2SYS Blog On Biometric Technology. M2SYS Blog On Biometric Technology, 02 Mar. 2018. Web. 15 May 2018.
[21] Farber, Dan. "Extreme Reality Turns Skeletons into Biometric Signatures." CNET. CNET, 27 July 2013. Web. 15 May 2018.
[22] Luke Robbins. (2018). What the Heck Is Hummingbad, and How Do You Stop It?. [online] Available at: https://lukerobbins.me/blog-posts/technology/what-the-heck-is-hummingbad-and-how-do-you-stop-it/ [Accessed 18 June 2018].
[23] Tom's Guide. (2018). When Does an Old Smartphone Become Unsafe to Use?. [online] Available at: https://www.tomsguide.com/us/old-phones-unsafe,news-24846.html [Accessed 15 May 2018].
[24] C. Allen and T. Dierks, “The tls protocol version 1.0,” 1999.
[25] T. Dierks, “The transport layer security (tls) protocol version 1.2,” 2008.

[26] Muller, Ian E. "What Does the Future of Biometrics Hold?" Veridium. N.p., 20 Feb. 2018. Web. 15 May 2018.

[27] Shibli, Masum, John Trader, and Mehedi Hassan. "Nissan Concept Car Features Fingerprint Identification." M2SYS Blog On Biometric Technology. M2SYS Blog On Biometric Technology, 02 Mar. 2018. Web. 15 May 2018.

[28] Zurier, Steve, Steve, and Google. "The Future of Biometrics Could Be in What You Type."Technology Solutions That Drive Education. N.p., 19 Apr. 2016. Web. 15 May 2018.

Model-driven Design of an Integrated Aircraft Test Set

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Abstract: Flying capability and performance of aircrafts depend heavily on the integrity and quality of internal measurement chains responsible for sensing and processing physical parameters of the environment and subsystems. However, high specialization of measurement and testing equipment in the aerospace industry has resulted to high testing costs, logistical issues, and increased exposure to risk of early obsolescence. We propose a Model Based Systems Engineering (MBSE) approach to the design of an Integrated Aircraft Test Set (IATS). It's shown effective in helping the systems engineer manage the complexity of integrating functionality and capabilities of existing commercial off the shelf (COTS) testing equipment into one test system. MBSE tool capabilities are leveraged to organize the model, document and manage requirements, describe system structure and behavior, drive engineering analysis, and conduct simulation. The methodology presented provides a simplified framework for maturing an operational concept to develop a virtual prototype and demonstrate functionality through simulation.

1 INTRODUCTION

1.1 Problem statement

Aircrafts, whether civilian or military, have been playing a central role in modern life. They are safety-critical systems whose ability to achieve flight and properly perform core functionality lies heavily on the accuracy, precision and speed of sensing and processing of environmental and subsystem physical parameters. Thus, establishing and maintaining the integrity and quality of measurement chains – from the sensors to the cockpit and autopilot – across the aircraft is critical to its proper and safe operation. Records of accidents from which subsequent technological advances have emerged point to significantly improved flight safety now (Noland & Peterson, 2019). Advances in aircraft inspection and testing systems have contributed to that aim and continue to help keep aircrafts safely in the air. However, design and development of testing systems within the aerospace industry poses a variety of challenges beyond the fundamental one of ensuring accuracy and precision of a multiplicity of measurements involving various physical quantities, components and systems performed by individual testing instruments. Most of current testing platforms are proprietary and are used to perform specific measurements as illustrated in Figure 1.a). This often results to costly, time consuming and logistically challenging aircraft maintenance and testing operations (EM, 2014). Moreover, the challenge is made even more difficult with the looming issue of obsolescence of aircraft, which trickles down to measurement and testing systems. As a new and improved technology emerges, the need for the capabilities to perform necessary maintenance tests to verify functionality emerges as well. However, constantly deploying new testing equipment is neither cost nor logistically effective for most organizations. This problem is particularly acute in military aerospace where the leadership "…would rather add a capability to an existing system rather than build [or buy] a new system, if possible." (Howard, 2016).

1.2 Scope and objectives

This paper contributes to the ongoing effort to tap into existing technological opportunities to address today's most present aerospace measurement challenges (Conway, 2003) (RS, 2015). We propose leveraging advances in electronics and computing to develop an Integrated Aircraft Test Set (IATS) capable of performing the various measurements currently requiring different test sets. Our design approach is model-driven and leverages emerging Model Based Systems Engineering (MBSE) capabilities to describe the architecture of the system and drive its analysis. We first conduct a short but comprehensive review of the state-of-the-art and various foundational topics and concepts relevant to this research. Next, we briefly describe our MBSE approach followed by its application to the design of a prototype IATS system. The paper concludes with a summary and future work to be performed.

2 BACKGROUND AND LITERATURE REVIEW

2.1 Integrity of the measurement chain

The avionics within an aircraft detect and measure relevant aspects of the aircraft's status and relay that information to the autopilot and the crew in the cockpit via the Multi-Function Display (MFD). Information relayed from the aircraft subsystems to the pilots include fuel level, engine oil pressure, engine oil temperature, stabilator position, among others. These physical measurements are detected using various sensors mounted/embedded on/in the equipment, and the given voltage signal is interpreted and processed throughout the measurement chain before being pushed to the MFD as pictured in Figure 1.b). They are used for decision-making and control of the aircraft. Thus, their accuracy, precision, reliability and timely transmission are critical for safe and efficient operation of the aircraft. Current state-of-the-art evaluation of the integrity of the measurement chain is mostly conducted with test (e.g., pressure, angle,..) and equipment (e.g., blade, stabilator,..) specific commercial off the shelf (COTS) measurement sets as illustrated in Figure 1.a). Reducing the number of sets as well as the test time without losing in accuracy and precision of test is an opportunity to significantly drive the cost of aircraft maintenance down while improving the efficiency of the process.

2.2 Integration challenge

The integration of the functionality of multiple test sets into one system is not an easy undertake. This is a complex challenge for which traditional, document-driven systems engineering approaches are ill-equipped to address. Moreover, the intrinsic and multifaceted complexity of aircrafts (and their test) systems adds to the difficulty of the task (Tamaskar et al., 2014). There has been little interest from researchers in investigating efficient design of test sets. Research efforts have seem to revolve around the leveraging remote sensing capabilities for measurement technologies as well as acquisition of wideband radio frequency (RF) for sensing (Daponte et al., 2014). Model-based systems engineering (MBSE) has recently emerged as a solution to the formalization of the practice of systems development through the use of models. The latter are the main artifact used to evaluate potential design solutions and system architectures while accounting for the resulting effects propagating throughout the system. MBSE procedures provide formal basis for: (1) Closing the gap between what is needed and how the system will work through the development of virtual prototypes, (2) Assisting in the management of complex systems, and (3) Early and formal approaches to system validation and verification. Thus, MBSE effectively provides means to manage the complexity of the design (Hart, 2015).

There is no unique "one size fit all" winning strategy for MBSE (Estefan, 2008). However, experience indicates that a combination of semi-formal and formal models leads to good solutions. Semi-formal models capture ideas (goal/scenarios) and preliminary designs represented in graphical languages such as the Unified Modeling Language (UML) and the System Modeling Language (SysML) (Fridenthal et. al, 2008). Models built with formal languages with precisely defined semantics provide computational support for detailed simulation of system behavior, and systematic design space exploration. Abstraction mechanisms enable system engineers to efficiently decompose system design at a given level of hierarchy into subsystems and components (decomposition), or alternatively, systematically assemble (composition) a system from predefined components. Thus, this approach provides a means to experiment with a model of the system – a virtual prototype – instead of a built prototype of the system. The benefits include considerable savings in cost and time.

3 MODEL BASED DEVELOPMENT FOR AN INTEGRATED AIRCRAFT TEST SET

3.1 Approaches and strategies

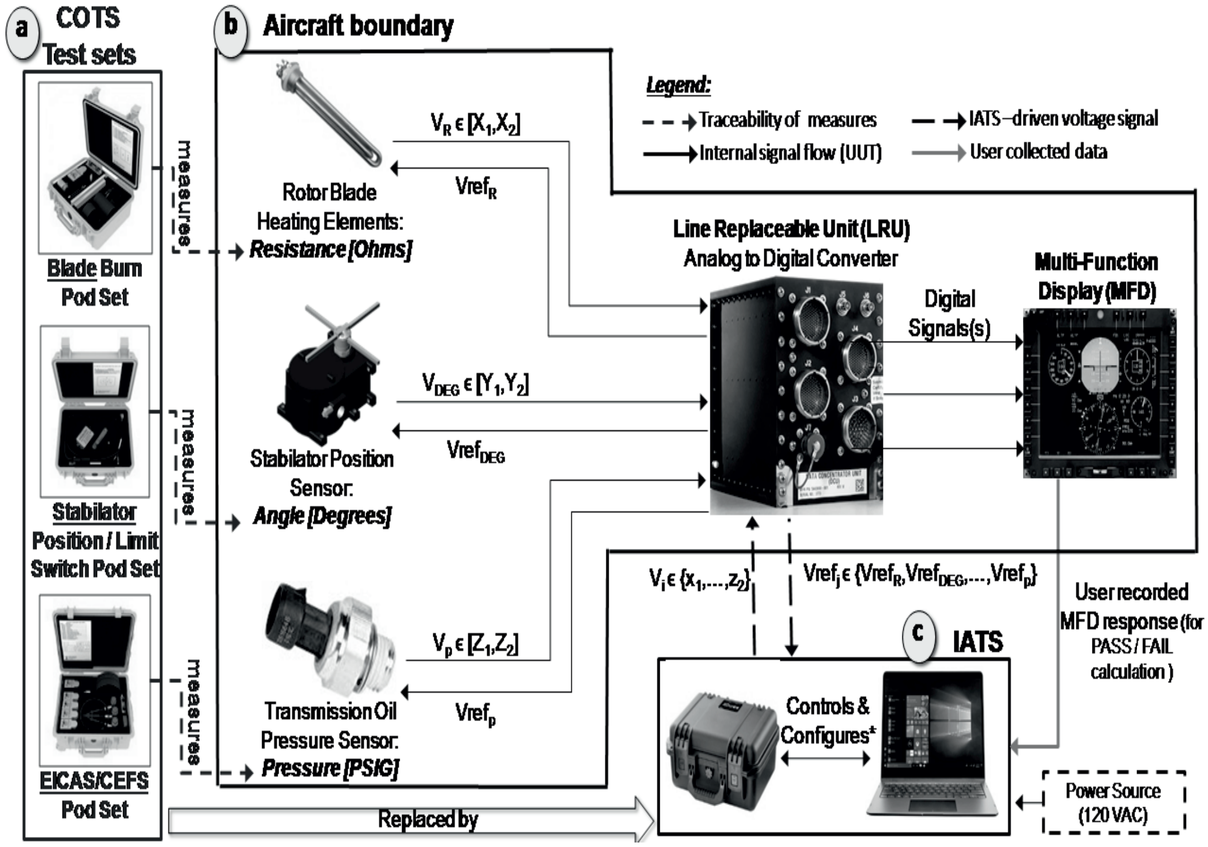


Figure 1. Illustration of aircraft measurement chains (b) along with traditional testing (a) and proposed IATS (c) systems

3.2 Elements of MBSE for the integrated test set design.

Figure 2 shows the pathway from an operations concept (OC) to simplified models for behavior and structure, requirements, system-level design and evaluation. From the high level OC, the designers work with the customer to

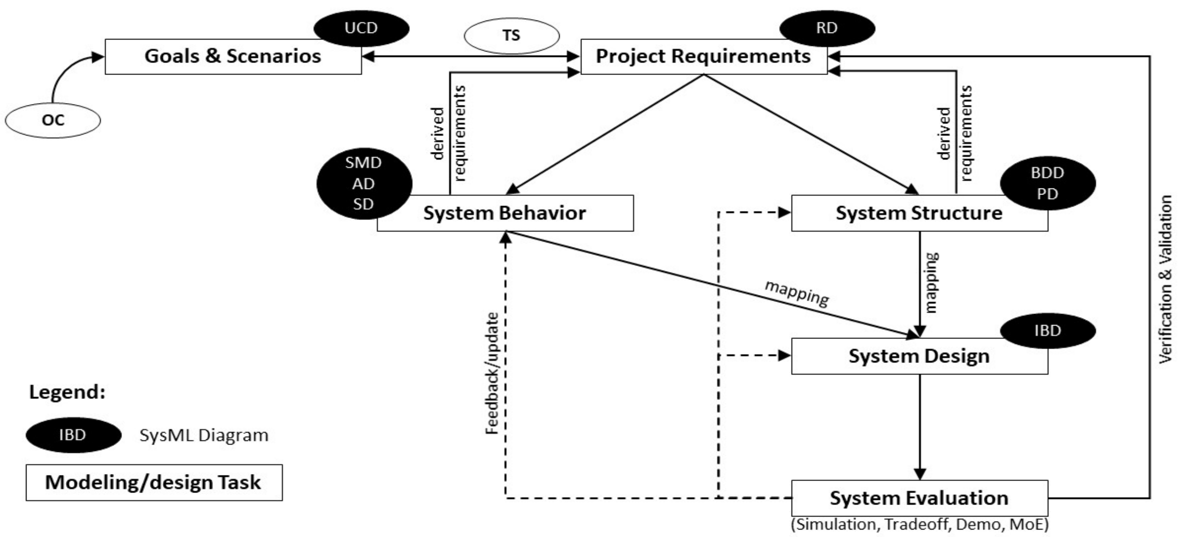


Figure 2. Simplified MBSE approach to system design and development

develop the new test system goals and scenarios. Resulting system functionality can be captured in a SysML Use Case diagram (UCD). It allows for the representation of system stakeholders as (primary and secondary) actors interacting with the system via association links. Detailed analysis of use cases in the context of operational scenarios (under the constraint of high level requirements) using textual scenarios (TS) enables the elicitation of new low level requirements from high level ones as well as new derived requirements. A requirement diagram (RD) is used to gather, organize and represent all the system requirements. It serves as a reference that guides the description of system structure and behavior. Aspects of the behavior to capture include the description of, (1) the control and data flow in the test set using an activity diagram (AD), (2) the message-based interactions between the active components of the test system using a sequence diagram (SD) and, (3) the behavior changes during a transition between states of the test set system when an event occurs using a state machine diagram (SMD). The definition view of the system structure provides its decomposition into subsystems and components along with attributes and is captured with the block definition diagram (BDD). Its usage shows the internal structure of the test set as well as components with their properties, operations and relationships. This is captured well by the internal block diagram (IBD). Through the specification of flows between subsystems/components in the IBD, the designer effectively integrates elements of the behavior and the ones of the structure. Another important integration mapping mechanism at the designer's disposal is the allocation of system behavioral elements (e.g., action) to its structural elements (e.g., subsystem, component) using "swimlanes" in an AD. Constraints between the structural elements of the test system as well as the mathematical formulation of physical phenomenon (e.g., energy conversions, etc.) are captured using the parametric diagram (PD). The latter leverages the system/component attributes (e.g., weight) in the BDD and stores the constraint using mathematical relations (i.e., equations). They could be used later to verify a system requirement regarding maximum total weight.

System evaluation is performed to better inform decisions within the architecture of the system and beyond. Simulations of the model are performed to evaluate the model logic but it can also be done to assess the adequacy of the system design thus, the verification of its requirements. Trade study is performed to determine the optimal set of components chosen with respect to the customer defined measures of effectiveness (MoEs). Various options of system components can be objectively analyzed using the appropriate analysis tools.

4 INTEGRATED AIRCRAFT TEST SET (IATS) SYSTEM DESIGN

4.1 Overview and operational concept

Maintaining fully mission-capable (FMC) status of military aircrafts is at the core of the United States Army Aviation Maintenance (US AAM) mission (Department of the Army, 2000). Thus, maintenance personnel must routinely perform testing procedures that troubleshoot and verify functionality of specific aircraft subsystems and Line Replaceable Units (LRUs) that are deemed critical for operation. The tests verify that each measurement chain, or unit under test's (UUT), measured response to known stimulus inputs fall within the calculated and expected range. Among the main measurement chains routinely tested are the Blade-ice heater mats, the Stabilator Limit Position Sensor and LRUs responsible for indications of vehicle health, such as engine oil pressure/temperature. Performing these tests currently requires the usage of multiple expensive pod sets and create a sprawling logistic footprint. Plus, the pod sets are test specific thus, prone to obsolescence. The purpose of this case study is to demonstrate how the proposed MBSE framework in Figure 2 can be used for the design of an Integrated Aircraft Test Set (IATS) to be used in lieu of several test sets as pictured in Figure 1.a) and c).

The IATS system integrates the capabilities of the existing COTS equipment into a modular design to allow for expandability. The system emulates the various sensors by manipulating and measuring the excitation (i.e., V_{refj}) and response (i.e., V_i) signal characteristics outside of the LRU system boundary. The response value is then measured by the LRU and used to determine what indication should be pushed to the MFD. Its indication can be compared against the test accepted response value for PASS/FAIL calculation according to the testing protocol.

4.2 Methodology and results

We employ MagicDraw's Cameo Enterprise Architect as the main architecting tool for advanced simulations and analysis. Together these tools allow us to explore the IATS design space to understand and identify feasible and infeasible designs. The problem is solved in five main steps implementing the methodology in Figure 2 as follows.

4.2.1 Model organization

In order to keep complexity in check as the model grows, we organize and align model artifact with the SysML decomposition of diagrams (i.e., requirements, use cases, behavior and structure). The model organization is augmented with existing and new libraries of components and objects that have the potential of being used across the model development (e.g., value types, profile of new stereotypes).

4.2.2 Requirements engineering

In collaboration with the customer (i.e., US AAM), goals and scenarios are developed from the high level operational concepts captured above. Then, high level functionality of system are fletched out and documented in a use case diagram. The one in Figure3 illustrates the core functionality of the IATS system with the main being to perform selected tests as needed. The actors associated with the system include the operator, technician, aircraft, and power source. The customer needs the IATS system to achieve greater than or equal performance compared to individual test sets. Other requests include that the system maintains a reasonable size and weight to increase portability. These desiderata are needs that are translated into high level requirements, then captured and organized in a requirement diagram. It plays a central role in helping the designer specify traceability with structure and behavior architectural artifacts (e.g., block representations), external analysis, and system test activities for the purpose of verification and validation. Use cases such as "Perform Test" are specified using textual scenario description and provide avenues to elicit specific ordered actions such a "Route Signal" and "Measure Signal Voltage". Also, analysis of abnormal flow of events leads to the identification of new and derived requirements such as acceptable ranges for accuracy (greater than 95%) and weight (less than 37 pounds) of the system.

4.2.3 System behavior and structure specifications

The IATS system is comprised of a maintenance laptop, breakout box, power converter, and interface cable set. They are further decomposed and their behavior (operations) identified and represented using a BDD. Measurement cards within the system measure incoming and outgoing signals. The control board, coupled with an embedded processor, make up the "brain" of the IATS system, enabling various configurations of the motherboard, which can hold up to seven daughterboards. The ability to control the signal routing through the motherboard and the signal manipulation through the daughterboard is critical to providing an integrated testing solution. Laptop and power converter are the main interfaces of the system with the User and the environment. Custom software running on top of the controller will replace the chassis of the existing COTS system. Utilizing the swimlanes within the AD, we allocate necessary actions to specific components within the BDD. For example the action of "Manipulate Signal" can be allocated to the daughterboard, while "Measure Signal Voltage" would be allocated to the measurement card. Such allocations are effective mean to realize the actual "system design" step in Figure 2. The software graphical user interface (GUI) provides means for the user to control the system, while automating the testing process to the maximum extent possible.

4.2.4 Engineering analysis

The IATS system can be represented with the simplified voltage divider circuit in Figure 4.The breakout box emulates the sensor by adjusting resistance of the variable resistor within the circuit and changing the conditioned signal voltage. The daughterboard manipulates the incoming excitation signal through the use of a digital potentiometer. The incoming/outgoing signal attributes are governed by the following set of equations:

(1) Power Equation:

$$Power = Voltage * Current$$

(2) Kirchhoff's Voltage Law (KVL):

$$\sum V = 0$$

(in a closed circuit loop)

(3) Ohm's Law:

$$Voltage = Resistance * Current$$

(4) % Error of Measured Value:

$$Error\ (\%) = \frac{|Measured\ Value\ - Accepted\ Value|}{Accepted\ Value} * 100$$

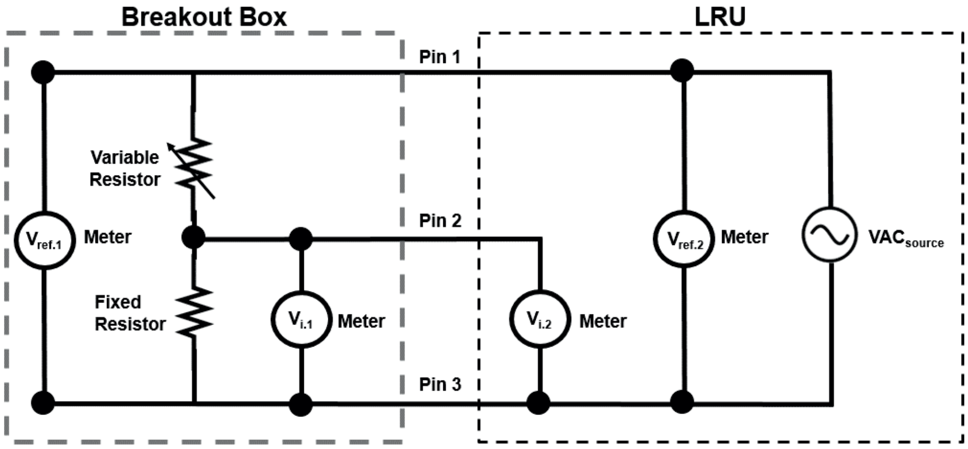
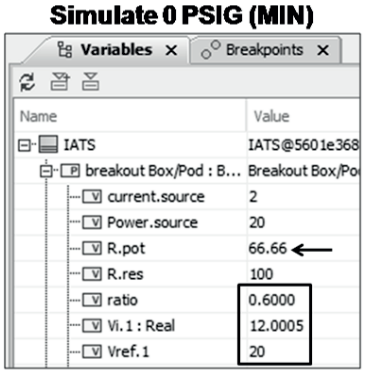


Figure 4. IATS sensor emulation circuit diagram

4.2.5 Simulation

We are interested here in the constraints (1) - (4) governing the electrical attributes of the incoming/outgoing signals between the aircraft UUT and IATS system during the test. We created a parametric diagram (PD) to capture and represent those constraints. Using an instance of the diagram, we vary the values of the variable resistor to adjust the output voltage of the conditioned signal. The simulation allows for a virtual prototype demonstration. Results from a simulation of the oil pressure measurement chain can be seen in Figure 5. The reference voltage ($V_{ref.1}$) provided from the LRU will be constant for a given measurement chain, however the response signal voltage ($V_{i.1}$) varies based on the selected value for the variable resistor (R_{pot}). The range of resistance settings available within the IATS allows for full emulation of the relevant sensor within the measurement chain (such as the oil pressure sensor), resulting in a range of possible response signal voltages. The resulting voltage ratios ($V_{i.1}$/ $V_{ref.1}$) measured by the LRU are directly equivalent to an oil pressure value. The voltage ratios are processed by the LRU and sent to the MFD as a digital signal representing the respective oil pressure value. Therefore, we can directly control the virtual oil pressure indication of the MFD by simply varying the resistance value within the IATS PD, as the results illustrate in Figure 5.

Simulate 0 PSIG (MIN)



Pressure to Voltage Ratio Chart

Pressure (PSIG)	$V_{ref.1}$	$V_{i.1}$	$V_{i.1}$ / $V_{ref.1}$
0 (MIN)	20	12.0	.600
20	20	11.5	.575
40	20	11.0	.550
60	20	10.5	.525
80	20	10.0	.500
100	20	9.5	.475
120	20	9.0	.450
140	20	8.5	.425
160 (MAX)	20	8.0	.400

Simulate 160 PSIG (Max)

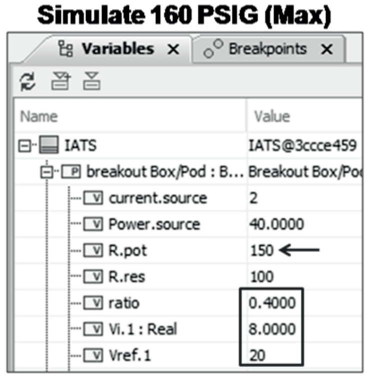


Figure 5. SysML parametric diagram simulation results

5 CONCLUSION

Our work uses the perspective of complex engineering systems to look at the technical challenge of integrating the functionality of several aircraft test sets into one testing instrument. Solving this challenge is critical in addressing pressing issues in aircraft maintenance and testing operations namely, especially high cost, time consuming testing and logistically demanding testing operations driven by the use of multiple test sets. We developed and used a simplified framework for model-based systems engineering (MBSE) to drive the designing and modeling of a novel Integrated Aircraft Test Set (IATS). The framework enables the development of architectural and engineering models of the system. Simulation of the model demonstrates value of the approach as well as the effective use of system thinking supported by MBSE techniques in addressing such a complex challenge. This effort has brought some light on the effective benefits and contribution of MBSE approaches to the ongoing effort improving productivity and reducing aircraft testing costs in large organizations such as the US AAM. More insight can be gained in future work through trade-off analysis leading to the selection of an optimal design and its formal verification.

REFERENCES

[1] Noland D. and Peterson B. (2017).*12 Plane Crashes That Changed Aviation*, Popular Mechanics, Retrieved from https://www.popularmechanics.com/flight/g73/12-airplane-crashes-that-changed-aviation/

[2] EM (2014).*Meeting Toughest Test and Measurement Challenges in Aerospace and Defence*, Electronics Maker, Retrieved from https://electronicsmaker.com/meeting-toughest-test-and-measurement-challenges-in-aerospace-defence

[3] Howard C. (2016).*Time to Invest in Test and Measurement Tools,* Military Aerospace, Retrieved from: https://www.militaryaerospace.com/articles/print/volume-27/issue-11/technology-focus/time-to-invest-in-test-and-measurement-tools.html

[4] Conway B. A. (2003).*Aerospace measurements: Challenges and opportunities*, Technical Report, NASA Langley Research Center

[5] RS (2015).*Meeting tomorrow's challenges,* Test *and measurement solutions for aerospace and defense*, Rohde & Schwarz

[6] Tamaskar S., Neema K., Kotegawa T.,& Delaurentis D. (2014).*Measuring Complexity of Aerospace Systems,* Research in Engineering Design, Volume 25, Issue 2, pp 125–137.

[7] [Daponte P., De Vito L., Rapuano S. and Tudosa I. (2014).*Challenges for aerospace measurement systems: Acquisition of wideband radio frequency using Analog-to-Information converters,* IEEE International Workshop on Metrology for Aerospace, Benevento, Italy

[8] Hart L. E. (2015), *Introduction To Model-Based System Engineering (MBSE) and SysML*, Delaware Valley INCOSE Chapter Meeting July 30, 2015

[9] Estefan J.A. (2008), *A survey of Model-Based Systems Engineering (MBSE)*, version 8, INCOSE MBSE initiative. INCOSE, 2008.

[10] S. Fridenthal, Moore A., & Steiner R. (2008).*A Practical Guide to SysML*. San Francisco, CA: Morgan Kaufman Publishers Inc.

[11] Department of the Army (2000), *Army Aviation Maintenance (FM 3-04.500),* Washington, DC:U.S. Government Printing Office.

Dashboard Development for Education for Minorities to Effectively Raise Graduation and Employment in STEM (EMERGE in STEM)

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Abstract: The current advancement of Underrepresented Minorities (URMs) in Science, Technology, Engineering, Mathematics (STEM) pathways is not enough to address underrepresentation in both colleges and the STEM workforce. EMERGE in STEM is a Design and Development Launch Pilot that aims to broaden participation (BP) and include URMs in the STEM workforce. Therefore, STEM events and software tools were introduced to grade 4 to 12 students in a high-poverty community, and their attitude to STEM subjects and 21st century skills were captured before and after these events in the form of surveys. To allow for easy access to the results, analysis and insights from the survey results among the numerous partners involved in the program, we developed dashboards to provide high-level summary and interactive visualizations of the survey data. These dashboards will be published on the EMERGE IN STEM website as a one-stop place for documented processes, tools and resources for other URM communities across the nation looking to replicate these efforts.

1 INTRODUCTION

Women, persons with disabilities, African Americans/Blacks, Hispanic Americans, American Indians, Alaska Natives, Native Hawaiians, Native Pacific Islanders, and individuals from low economic backgrounds have been historically underrepresented and underserved in several fields of science and engineering at all levels – ranging from pre K-12 to long-term participation in the workforce (NASEM, 2011; Malcom & Freder, 2016). Yet, some organizations have posited the inclusion of talent from every sector of the American Society is needed for a healthy science and engineering community and its continual relevance to society (NSF, 2017). As a result, the National Science Foundation launched the Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INLUDES) initiative to tackle this national challenge by deploying national solutions.

Education for Minorities to Effectively Raise Graduation and Employment in STEM (EMERGE in STEM) is a Design and Development Launch pilot that aims to 1) broaden participation and inclusion of Underrepresented Minorities (URM) in the STEM workforce, 2) increase student exposure to exciting STEM career knowledge and opportunities for students throughout grade 4 to 12, and 3) demonstrate a collective-impact process to facilitate expansion of alliances that foster broadening participation at the national level. The pilot aims to impact women and at-risk minority groups in a high-poverty community in North Carolina facing peculiar challenges like low economic levels, ineffective parental advice, among others. The grade 4-12 continuum was chosen for the pilot owing to previous research that have shown that thoughts of career are present by the time a student enters high school, and students' decision to enter a STEM-oriented college program or job function becomes intentional when they graduate from high school (Akos et al., 2007; UMASS, 2011).

The EMERGE in STEM pilot leverages a network of strategic partners with profound diversity goals and unique perspectives including K-12 school district, community colleges, universities, local industry, educational software developers and the state Department of Education to solve a URM STEM-inclusion problem. Several thousand middle-school URM participants including women and the deaf are being introduced to *Learning Blade*, an educational STEM software. Some of these students also participate in STEM focused events to increase their exposure to STEM disciplines and make them aware of career opportunities in the STEM workforce. The impact of these efforts will be measured by administering survey instruments - MISO Upper Elementary S-STEM Survey and the MISO Middle/High S-STEM Survey (Friday Institute, 2012a and 2012b) – before and after participation. Some of the data collected include key demographics, student attitudes measured on a five-point Likert Scale, and student interest in STEM careers. One of the challenges is to present the data in an effective way since the overwhelming amount of the data could be difficult for administrators to have any meaningful use. Visualization offers a possible solution to this problem and have been used in various projects.

Gupta et al. (2004) used several visualization tools to display data collected about dental student learning. They used pie chart to display the student's opinion about ease of access to computer clusters during the learning process. Annesley (2010) has suggested that pie charts be used for visual representation of discrete or nominal discontinuous variables. According to Ng and Peh (2009), pie chart should be used to show classes or groups of data relative to the entire data set. The whole pie represents all the data and the slices of the pie show a different class or group as a proportion of the whole. They suggested that each slice should display significant variations. The number of divisions should range between three and ten. For example, they used pie chart to show the distribution of various types of tumors. In this research, pie chart was used to display proportion of each gender in the data.

Even though exact values of data can be presented in tables, the line chart is a useful visualization to understand the patterns that underlie those data values. The line chart is similar to the scatter diagram except that the values of the variable have a unique sequence. The line chart can represent several dependent variables on a single graph. Line graphs usually are designed with the dependent variable on the Y-axis and the independent variable on the horizontal X-axis (Ng and Peh, 2009). Ferrin et al. (2004) used the line chart to show hospital room hospitalization and the average number of patients waiting over a specific period. Bar charts have been used to represent data sets including energy consumption, food insecurity, surgical procedures and student learning. Streit and Gehlenborg (2014) stated that bar charts are appropriate for counts and stacked bar chart are suited to illustrate the contribution of each category to the total.

This research aims to develop interactive dashboards to visualize the survey data and present analytical results.

2 APPROACH

Interactive Dashboards were developed using the knowledge of visual analytics that can enhance analytical reasoning using interactive visual interfaces (Wong and Thomas, 2004). This comprises data analytics, visualization and interactivity (Desai, Jiang & Davis, 2014). Appropriate visualization tools were chosen for the interactive dashboards based on best practices outlined in the literature. In this research, we used bar chart to represent the score of each school grade (e.g. grade 11 and 12) for several subjects.

Data Visualization software, Tableau® was used to develop the interactive dashboards. Tableau Server is an online hosting platform that holds all workbooks, data sources associated with a visualization. The dashboards developed in this research will be published on the EMERGE in STEM website which is accessible to all partners in the research (colleges and universities, school districts, community organizations, external evaluators, entrepreneurs and the industry). The aim is to provide a Go-To hub of STEM information where partners direct their memberships and constituents. The comprehensive website will be useful to build and share capacity across the community (in the county and around the nation) for information on broadening URM participation in STEM, or for communities looking to replicate these efforts across the nation.

3 INTERACTIVE DASHBOARDS

3.1 Dashboard Homepage

Based on review of literature we used bar charts, pie chart and line chart as the visualization tools for the dashboard because of their appropriateness for the data. Figure 1 shows the first page of the dashboard – the homepage. It displays general information about what the user will see in the succeeding dashboards, the navigation buttons to the overview page and buttons to the survey results for each of the schools for which data was collected.

3.2 EMERGE in STEM Data Overview

The *overview* dashboard shows the brief description of the data. Survey instruments were administered to measure student awareness of career opportunities, attitude towards science, math, engineering and 21st century skills, and interest in pursuing STEM careers. The data contains the responses from student participants (in grade 4-12) who were exposed to STEM related activities, outreach programs or used software tools. This was to develop their interest in STEM disciplines and excite them about becoming part of the future STEM workforce with the aim of broadening participation in the workforce. Since the target population is underrepresented minority students (URM), we use pie charts to show the percentage of students from the survey that belong to each racial group (African American, Hispanic, American Indian, Alaska Native etc.). We also used pie chart to show the percentage of male and female in the group since the research also focused on improving women participation. We used bar chart to show the number of students that participated from each school surveyed. The overview dashboard is shown in Figure 2.

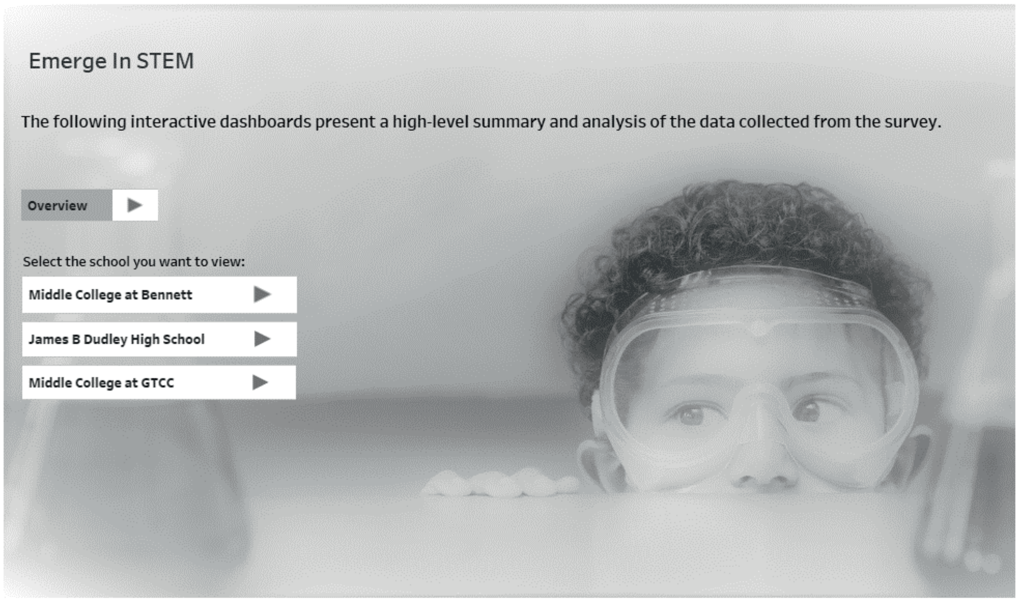

Figure 1: Dashboard Homepage

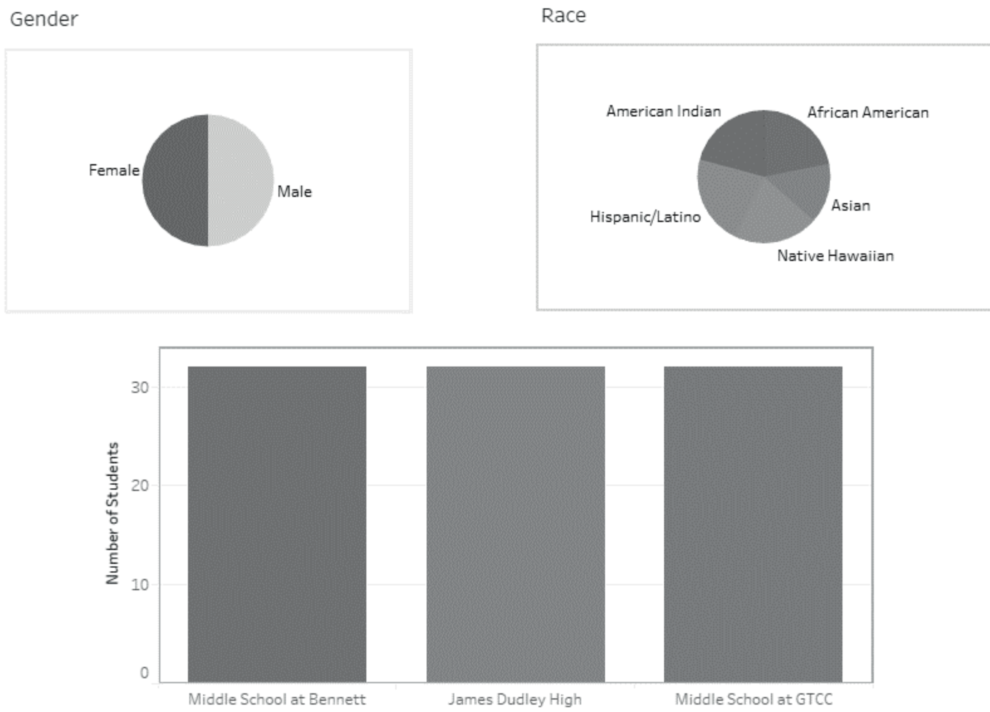

Figure 2: Overview Dashboard

3.3 Participating School Dashboards

This dashboard shows the visualization for each participating school. Each school has a separate dashboard and the user can navigate to the school page directly from the homepage. However, the user can also see the dashboard for other schools from the currently active school dashboard by using the appropriate filters in the right pane. Using a five-point Likert scale, students were asked to rate their attitudes towards math, science, engineering and technology, and 21st century skills. In the ***School Grade*** window, we use bar charts to show the average scores for each subject the respondents were asked questions about. This average score is then classified by grade.

In the ***Student Scores*** Window, a line chart shows the average scores for each student (with unique ID) for each subject. When the user hovers over the line chart, a tool tip shows the average score for each student. This gives a sense of how each student's scores compare to each other for all subjects. The line chart will also allow the user to identify if there are any observable patterns in the distribution of the average scores of the student.

In the ***Gender*** window, the user has the option to view the score averages for each gender together or separately by using the checkboxes in the filters pane. The user can compare the average scores of both gender to the questions before and after the survey to observe if there are any differences before the student attended the event and after they do so. The filters in the right pane also allows the user to see data specific to a school grade (e.g. grade 7 vs grade 8) or one gender at a time depending on what information they are looking to see. The gender window is shown in figure 3.

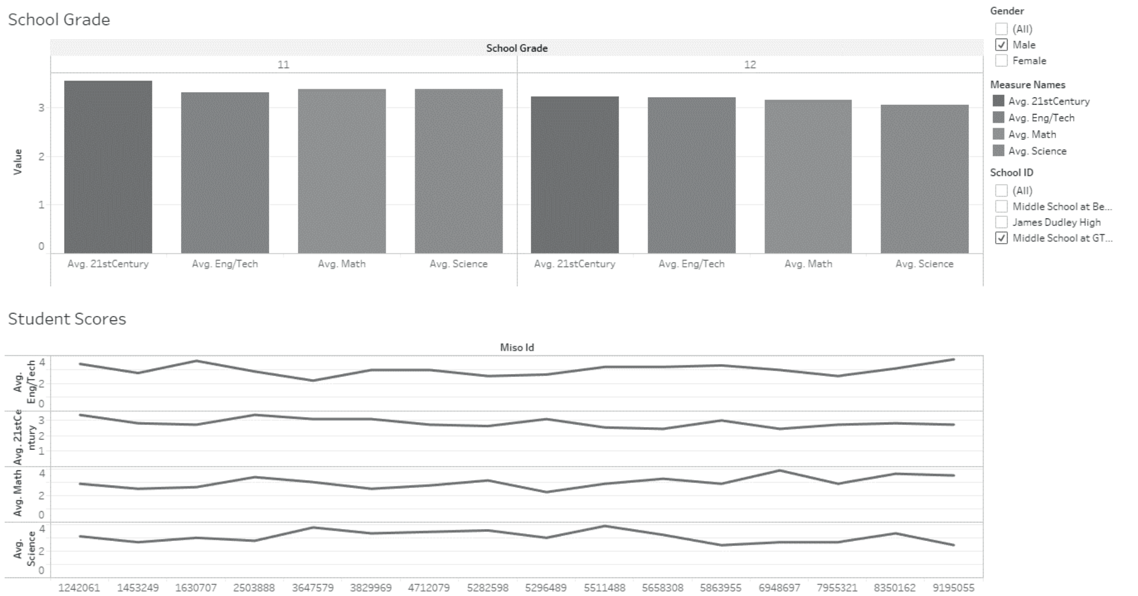

Figure 3: School Dashboard: School Grade and Student Scores Window (Middle School at Bennett)

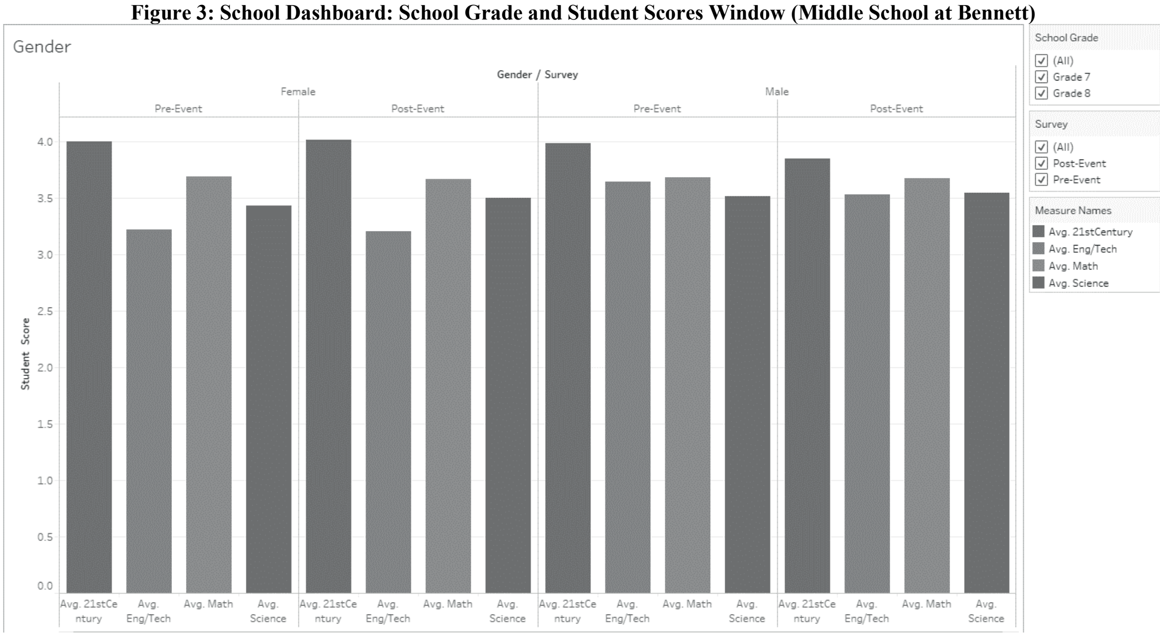

Figure 4: School Dashboard: Gender Window (James Dudley High)

4 DISCUSSION AND CONCLUSION

Attracting more URMs in the STEM workforce is an important task. EMERGE in STEM addresses this problem through a series of events and the use of learning software tools to improve the awareness of the grade 4 to 12 students in a local high-poverty community. To effectively present data collected from the project, dashboards were developed to provide interactive visualizations to assist the administrators assess the impact of the program and make informed decisions.

One of the limitations of the current study is the limited data collected from the project since many events are still underway. In the future, statistical analysis such as paired Hotelling's T^2, profile analysis, and confirmatory factor analysis will be performed and predictive modeling such as logistic regression will be developed. These analytical results will be visualized and included in the interactive dashboards.

REFERENCES

[1] National Academies of Sciences, Engineering, and Medicine. (2011). Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads. National Academies Press. Washington, DC.

[2] Malcom, S., Feder, M. (Eds.). (2016). Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways. National Academies Press. Washington, DC.

[3] Akos, P., Lambie, G. W., Milsom, A., & Gilbert, K. (2007). Early adolescents' aspirations and academic tracking: An exploratory investigation. Professional School Counseling, 11(1), 57-64.

[4] UMASS Donahue Institute, Research and Evaluation Group. (2011). Increasing Student Interest in Science, Technology, Engineering, and Math (STEM): Massachusetts STEM Pipeline Fund Programs Using Promising Practices. Prepared for the Massachusetts Department of Higher Education

[5] NSF INCLUDES Coordination Hub. (2017). Program Solicitation. NSF 17-591.

[6] Friday Institute for Educational Innovation (2012). Middle and High School STEM-Student Survey (S-STEM). Raleigh, NC.

[7] Friday Institute for Educational Innovation (2012). Upper Elementary School STEM-Student Survey (S-STEM). Raleigh, NC: Author.

[8] Wong, P. C., Thomas, J. (2004). Visual Analytics. *IEEE Computer Graphics and Applications*, Vol 24, No. 5.Pp. 20–21

[9] Gupta, B., White, D. A., & Walmsley, A. D. (2004). The attitudes of undergraduate students and staff to the use of electronic learning. British Dental Journal, 196(8), 487-492.

[10] Desai, Y., Jiang, S., Davis, L.B. (2017). Development of a Dashboard for a Local Food Bank. American Journal of Engineering and Applied Sciences. 10 (1): 218.228.

[11] Ng, K. H., Peh, W.C.G. (2009). Preparing effective illustrations. Part 1: graphs. Singapore Medical Journal. 50(3):245.

[12] Annesley, T.M. (2010). Bars and pies make better desserts than figures. Clin. Chem., 56: 1394-1400. DOI: 10.1373/clinchem.2010.152298

[13] Streit, M., & Gehlenborg, N. (2014). Points of view: Bar charts and box plots. Nature methods, 11(2), 117.

[14] Ferrin, D. M., Miller, M. J., Wininger, S., & Neuendorf, M. S. (2004). Analyzing incentives and scheduling in a major metropolitan hospital operating room through simulation. In Simulation Conference, 2004. Proceedings of the 2004 Simulation Conference, Winter 2.

An After School Engineering Outreach Program For Elementary Aged Children

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Abstract: In an effort to educate elementary school children about engineering and make them aware of gender stereotypes and how they can affect career decisions, the Center for the Advancement of Women in Engineering at the University of North Florida collaborated with a YMCA after school co-ed program. Engineering college students developed material for the program, including a presentation discussing what engineering is, how it benefits society, and how it is appropriate for both genders. The presentation also shared some of the gender stereotypes children encounter and how these can influence decisions made in life. The educational program included hands-on engineering design activities to engage the children and encourage problem solving. The first activity involved making a simplified hand using inexpensive materials. The second activity was to design and make a faraday flashlight with supplied materials.

1 INTRODUCTION

The United States is 20th in the world when it comes to gender equality according to the Global Gender Gap Index [1], and the American Association of University Women (AAUW) reported that women made up 12% of the engineering workforce in 2013 [2]. The Women in STEM: A Gender Gap to Innovation Report by the U.S. Department of Commerce Economics and Statistics Administration [3] suggests that factors contributing to the low percentage of women in STEM include gender stereotyping and a lack of female role models [4]. Specifically, gender identity may conflict with other social identities, such as being an engineer [5], which can contribute to self-stereotyping and lower confidence [6], can cause stress and steer girls and women away from STEM fields [7-9], and can even reduce the individual's performance in those contexts [7, 8]. In efforts to improve the gender equality in Engineering, and STEM in general, The Center for the Advancement of Women in Engineering (CAWE) was established at the University of North Florida.

2 THE CENTER FOR THE ADVANCEMENT OF WOMEN IN ENGINEERING

The mission of The Center for the Advancement of Women in Engineering is to implement strategies to recruit, retain, and advance women in Engineering. These strategies are based on research and as CAWE implements new strategies and researches the success of these, additional data will allow for continuous improvement. In the area of recruitment, CAWE provides outreach activities for children in grades K-12; in retention of female students though college, CAWE provides coaching and mentoring opportunities with industry members, faculty, and peers; and in aiding the advancement of women in the engineering community, CAWE develops strong relations with industry and brings representatives from community organizations together to share their experiences and how to move forward together. This paper focuses on some of the efforts implemented to educate children about engineering though an outreach program hosted in collaboration with YMCA of Florida's FIRST Coast, Inc.

3 YMCA-CAWE PROGRAM

YMCA of Florida's FIRST Coast, Inc. collaborated with CAWE to develop an afterschool outreach program for their K-5 community. This partnership provided opportunities to engage approximately 300 children in engineering activities in eight different schools. The activities were designed by college students and two to three college students together with YMCA employees led the activities with the children. The activities consisted of a presentation on what engineering is and how it relates to humanity, discussions on gender equality in engineering, and hands-on activities.

3.1 Engineering presentation

The presentations began with an overview of what engineering is, the types of engineering disciplines available, and what engineers do. It was emphasized that engineers design, develop, and build; that they are problem solvers. After the introduction to engineering, gender misconceptions were discussed.

One of the reasons few girls consider engineering as a profession is because females tend to choose professions in which they see a strong link between what they do and how it helps humanity. The link between helping society and engineering is not always easily evident. Therefore, in efforts to increase the interest of engineering among the girls, the engineering-humanitarian connection was emphasized during the presentation. For example, images of biomedical devices and products bringing people together were shared with the children, as were images of people from a hundred years ago who didn't have the benefits of some of today's technologies.

In efforts to ensure the children understand that engineering is suitable for persons, regardless of gender, the presentation discussed some common gender stereotypes. Children were shown images of engineers of different races, genders, ages, and physical abilities and it was shared with them that regardless of what group(s) you identify with, you can be an engineer. These differences provide us with unique ways of thinking and diversity of though results in better identifying the most pressing problems and help develop the most creative solutions. The children were also shown images of common media messages shared with children and asked them to comment on the differences between the messages shared with girls and those shared with boys. The messages shared with girls emphasized beauty, whereas the messages shared with boys emphasized what they are capable of becoming. It was suggested to the children that they should be critical in looking at messages shared with them so that they can make their decisions about their careers and lives based on what they want to do and are capable of doing, rather than what society suggests for them.

3.2 Engineering projects

The children were engaged in hands-on projects that provided them with opportunities to work together, problems solve, and develop solutions with provided materials. One of the projects were to develop a prosthetic hand and another to develop a Faraday flashlight. These projects were a fun way to engage the children with some introductory engineering activities.

3.2.1 Prosthetic hand

A large wood structure of a hand model was brought to the children with which they could engage. The model consisted of a wood piece modeling the arm and hand, and wood components for each of the phalanges. These were connected with plastic tubes, which held strings inside of them, acting as tendons. By pulling on the strings, the children were able to open and close the hand. After exposure to this model, the children were given material to create their own prosthetic hand. They were provided cardboard, straws, strings, plastic gloves, and tape. The straws would mimic the bones, and a slit was cut to help the fingers flex. The children proceeded by bringing the strings though the straws to act like tendons, and the tape was used for to attach the fingers with each other; the glove was placed above the other components, to make the assembly look like a hand. This activity was fun for the children and allowed them to utilize their problem solving skills – to think like an engineer – by developing a product intended to help humanity. The wood hand model and one of the children's models are shown in Figure 1.

3.2.2 Faraday flashlight

The concept of electricity was introduced to the children and it was discussed what the world may have been like before electricity. With Faraday's discovery of electromagnetic induction, electricity revolutionized the world by bringing lights to homes and a new way to power industries. The college students explaining Faraday's law to the children to help them understand that they could generate electricity by changing the magnetic field. They were provided with materials to build their own Faraday flashlight, consisting of magnets, a light emitting diode (LED), a plastic tube, and approximately 500 ft of magnet wire. They were able to light the LED by coiling the wire around the tube, connecting the ends of the wire to the LED, placing the magnets inside of the tube, and by changing the magnetic field though shaking their flashlight.

The children were challenged to find ways to improve their designs and they learned that increasing the amount of wire was one way to improve the functioning of the flashlight. This project provided a fun way for the children to engage with engineering, opportunities to problem solve, and team work on a project that connects engineering with helping humanity – here by bringing us light.

Figure 1: Hand display model and children's hand model

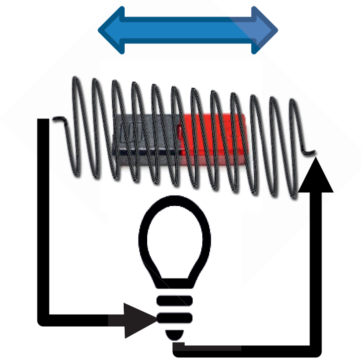

Figure 2: Faraday flashlight generated by shaking of coiled wire with internal magnet

4 EVALUATION OF ACTIVITIES

The YMCA-CAWE project provided children the opportunity to learn about engineering, connect engineering with humanity, learn about gender biases and how to overcome them, and the opportunity to problem-solve though hands-on engineering projects. It was evident that the children enjoyed these activities and to ensure that future activities continue to improve the children's understanding of engineering and that they can pursue a career in engineering regardless of gender, CAWE has developed IRB approved research instruments to measure the effectiveness of these programs. These evaluation instruments were used in a similar program with girls and suggests that even brief exposure to hands-on engineering experiences with a humanitarian focus contributes to children's increases in interest in STEM and knowledge about engineering. Specifically, children's self-ratings of their interest in math, science, and a desire to consider an engineering career significantly improve from pre-program to post-program participation. After the program, children also reported significantly increased beliefs in their knowledge of what engineering is, whether they are good at engineering, the belief that engineering can serve to make lives better, and that the types of jobs engineers can do are varied. Children maintained these higher levels of interest and beliefs in comparison to their pre-program ratings across a 6-month period, suggesting that even a brief educational exposure may have long-term implications for recruiting girls to engineering.

5 SUMMARY

In summary, the field of engineering is severely underrepresented by women, resulting in an underutilization of human capacity and diversity of thought. In efforts to increase the participation of women in engineering, The Center for the Advancement of Women in Engineering at the University of North Florida was created. The mission of CAWE is to recruit, retain, and advance women in engineering. One mechanism to recruit women to engineering is though outreach in the K-5 community. In the work presented herein, children in this age group were exposed to engineering activities in an afterschool program though YMCA. This program provided presentation on what engineering is, the engineering-humanitarian connection, gender biases and how to overcome them, and hands-on engineering activities. Similar outreach efforts have been conducted by CAWE in which the effectiveness was measured through IRB approved surveys. The results indicate that the efforts have a positive effect in educating the children about engineering and increasing the likelihood that girls will consider engineering as a viable career.

6 ACKNOWLEDGEMENT

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REFERENCES

[1] World Exonomic Forum. Available: http://reports.weforum.org/global-gender-gap-report-2014/rankings/.
[2] AAUW (2015). Solving the Equation: The variables for Women’s Success in Engineering and Computing. Washington, DC
[3] D. Beede, T. Julian, D. Langdon, G. McKittrick, B. Khan and M. Doms, "Women in STEM: A Gender Gap to Innovation," Administration, U.S. Department of Commerce Economics and Statistics, August 2011.
[4] Master, A., & Meltzoff, A. (2016). Building bridges between psychological science and education: Cultural stereotypes, STEM, and equity. Prospects (00331538), 46(2), 215–234. https://doi-org.dax.lib.unf.edu/10.1007/s11125-017-9391-z.
[5] S. Sinclair, C. D. Hardin and B. S. Lowery, "Self-stereotyping in the context of multiple social identities," J. of Personality and Social Psychology, vol. 90 (4), 2006.
[6] B. Simon, D. L. Hamilton, "Self-stereotyping and social context: The effects of relative in-group size and in-group status," J. of Personality and Social Psychology, vol. 66(4), 1994.
[7] S. Ahlqvist, B. London and L. Rosenthal, "How Unstable Identity Compatibility Undermines the Success of Women in STEM Fields.," Psychological Science, vol. 24 (9), 2013.
[8] Schwery, D., Hulac, D., & Schweinle, A. (2016). Understanding the gender gap in mathematics achievement: The role of self-efficacy and stereotype threat. School Psychology Forum, 10(4), 386–396.
[9] S. Ahlqvist, "Reducing the Gender Gap in Science, Technology, Engineering, and Math Fields: Developmental and Experimental Extensions of the Perceived Identity Compatability Model," Stoney Brook University, 2014.

Supporting Supply Chain Responsiveness through SCM Practices: Exploring Dimension Level Effects

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Abstract: Extending Thatte, et al.'s (2013) research model which found positive relationships between supply chain management (SCM) practices and supply chain responsiveness (SCR) and employing regression analyses, this paper analyzes the effects of specific SCM practices (SCMP) that impact SCR and its dimensions. The study finds that customer relationship (CR) and strategic supplier partnerships (SSP) are found to positively influence operations system responsiveness (OSR), while SSP and information sharing (IS) are found to improve supplier network responsiveness (SNR). IS, SSP, and CR between supply chain trading partners were found to increase SCR. The study did not find any support between SCMP dimensions and logistics process responsiveness (LPR).

Keywords: supply chain responsiveness, operations responsiveness, supplier responsiveness, logistics responsiveness, supply chain practices

1 INTRODUCTION

Thatte et al. (2013) dealt with large-scale instrument validation and hypotheses testing between SCR, SCM practices, and competitive advantage (CA) using structural equation modeling, and established a positive relationship between SCM practices and SCR, SCR and CA, and SCM practices and CA. This study extends the study of Thatte et al. (2013) by examining the dimension level relationships between SCM practices and SCR in order to understand how SCR can be improved through different SCM practices. Existing literature lacks such dimension level analyses involving SCM practice and SCR. This study aims at filling this gap by providing insight into these relationships, so meaningful practical implications for improving SCR and its three dimensions OSR, LPR, and SNR, via specific components of supply chain practices, may be drawn. The relationships between the constructs are tested using regression analyses using data from 294 survey respondents.

2 RESEARCH FRAMEWORK AND LITERATURE

Figure 1 presents the framework for this research. It has been adopted from Thatte et al.'s (2013) study, which developed the SCR construct and a valid and reliable measurement instrument for SCR through rigorous statistical methodologies, including pre-testing, pilot testing, confirmatory factor analysis, unidimensionality, reliability, validity, and second-order construct validation.

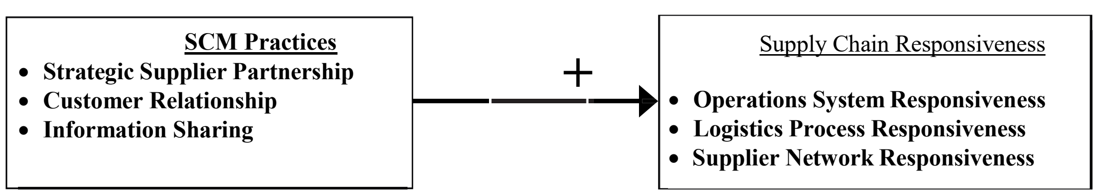

Figure 1. Research framework

2.1 SCM Practices

'SCM practices' is defined as "the set of activities undertaken by an organization to promote effective management of its supply chain" (Li et al., 2006, p. 109). Li et al. (2005, 2006) proposed 'SCM practices' as a multi-dimensional construct comprising upstream and downstream supply chain sides. This study adopts strategic supplier partnership, customer relationship, and information sharing as the three sub-constructs for SCMP as identified by Li et al. (2005, 2006). Li et al. (2005) developed a valid and reliable SCMP measuring instrument. This instrument is adopted in this study. SCMP has been shown to positively impact SCR (Thatte et al., 2013).

SSP is defined as "the long term relationship between the organization and its suppliers. It is designed to leverage the strategic and operational capabilities of individual participating organizations to help them achieve significant ongoing benefits" (Li et al., 2006, p. 109). Croxton et al. (2001) consider SSP as a key SCM practice. Gunasekaran et al. (2001) claim that a strategic partnership emphasizes long-term partnerships and promotes mutual planning and problem-solving efforts. Organizational strategic partnerships promote shared benefits and ongoing collaboration in key strategic areas. Strategic partnerships with suppliers make it easier for organizations to work closely and effectively with a few suppliers rather than multiple suppliers selected on the basis of costs alone (Kalwani and Narayandas, 1995). Cost-effective design alternatives, help in selecting better components and technologies, and assist in design evaluation are some of the benefits of including suppliers early in the product design process (Tan et al., 2002; Fulconis and Paché, 2005). Porter (1980) suggested that cooperation could enable partners to come together in a stronger position than they alone could. Mentzer et al. (2001) suggest that having closer ties with suppliers is the key to effective management in the global environment. Effective SCM requires cooperation between the supply chain members (Boddy et al., 2000). The past three decades have seen an increasing trend in long term, collaborative relationships by organizations with a few trusted suppliers.

CR is defined as "the entire array of practices that are employed for the purpose of managing customer complaints, building long-term relationships with customers, and improving customer satisfaction" (Li et al., 2006, p. 109). CR is regarded as a key SCM practice in literature (Noble, 1997; Tan et al., 1998; Croxton et al., 2001). The CR practices of an organization can affect both their success in SCM efforts and their performance (Scott and Westbrook, 1991; Ellram, 1991; Turner, 1993). Successful SCM involves downstream customer integration and upstream supplier integration (Tan et al., 1999). Personalized customer care and better customer relationship management are of paramount importance for organizational success (Wines, 1996). Good relationships with trading partners, including clients, are key to organizations ' successful SCM efforts (Moberg et al., 2002). Close customer relationships enable product differentiation from competitors, support customer loyalty, and increase customer value (Magretta, 1998). In developing effective SCM strategies, customer relationship activities have played a crucial role (Wisner, 2003).

IS refers to "the extent to which critical and proprietary information is communicated to one's supply chain partner" (Li et al., 2006, p. 110). Mentzer et al. (2000) mention that shared information may vary in nature from strategic to tactical, and could be related to logistics, customer orders, forecasts, schedules, markets, or other. The sharing of information refers to the access to private data between trading partners, enabling them to monitor the progress of products and orders through different supply chain processes (Simatupang and Sridharan, 2002). Simatupang and Sridharan (2005) provide some of the components of IS, including data acquisition, processing, storage, presentation, recovery and transmission of demand and forecast data, inventory status and locations, order status, cost-related data and performance status. They add that the IS for key performance metrics and process data improves the visibility of the supply chain, thereby enabling effective decision-making. They also state that shared information in a supply chain is only useful if relevant, accurate, timely and reliable (Simatupang and Sridharan, 2005). IS with trading partners allows organizations to make better decisions, take action on a more visible basis (Davenport et al., 2001), and is a critical element of a positive supply chain relationship (Lalonde, 1998).

2.2 Supply Chain Responsiveness (SCR)

SCR is defined as the capability of promptness and the degree to which a supply chain can address changes in customer demand (Holweg, 2005; Prater et al., 2001; Lummus et al., 2003; Duclos et al., 2003). SCR is aggregate of three first-order constructs operations system responsiveness (OSR), logistics process responsiveness (LPR), and supplier network responsiveness (SNR). OSR, LPR, and SNR were conceptualized and operationalized as the three sub-constructs of SCR in Thatte et al. (2013).

OSR is defined as the ability of a firm's manufacturing system to address changes in customer demand (Thatte et al., 2013). While OSR includes manufacturing and service operations, this study is limited to firms within the manufacturing industry. OSR at each supply chain entity is an essential constituent of SCR, as each entity is required to provide timely and reliable provisioning of products and services, to satisfy customer demand (Lummus et al., 2003; Duclos et al., 2003; Meehan and Dawson, 2002). OSR items measure the responsiveness of a specific node or firm in a supply chain (Lummus et al., 2003; Duclos et al., 2003).

LPR is defined as the ability of a firm's outbound transportation, distribution, and warehousing system (including 3PL/4PL) to address changes in customer demand (Thatte et al., 2013). These activities include packing and shipping, warehousing, transportation planning and management (Lummus et al., 2003; Duclos et al., 2003; Ricker and Kalakota, 1999), order tracking and delivery, inventory management, and reverse logistics. This study is limited to the outbound logistics of the focal firm. It is vital that firms have easy access to various modes of transportation and are able to utilize them for improving logistics flexibility and responsive (Prater et al., 2001). Firms' logistics should be able to adjust the logistics resources speedily so as to satisfy market needs (Hise, 1995).

SNR is defined as the ability of a firm's major suppliers to address changes in the firm's demand (Thatte et al., 2013). Firms' ability to be responsive to customer demand is also dependent on suppliers' ability to make volume changes. The presence of flexible and responsive partners downstream and upstream of a firm is essential for responsiveness (Christopher and Peck, 2004). Supply chains must be able to swiftly adapt to supply disruptions (Walker, 2005) as well. CA from a responsive supply chain can be gained through speedily meeting changing customer demands. This could be in the form of promptly supplying new products or satisfying the product volume, mix, variations, or new product introduction needs of the markets. Satisfying these requirements necessitates a responsive supply chain from raw materials to finished products and extending to distribution and delivery. Selecting suppliers who can quickly add new products and having suppliers make desired changes is detrimental to a firm's responsiveness. Selecting suppliers based on their capabilities impacts delivery time of new products (Choi and Hartley, 1996). A firm's ability to be responsive is weakened due to the lack of supplier flexibility (Holweg, 2005).

3 RESEARCH METHODOLOGY

This study adopts the SCR instrument developed by Thatte et al. (2013) and SCM practices instrument from Li et al. (2005) and Li et al. (2006). The unit of analysis in this study is a firm since SCMP and SCR rely on the individual operating companies within a supply chain. A similar unit of analysis has been used in previous studies (ex: Swafford et al., 2006). A study that involves the entire supply chain, from raw materials to end customer, would be complex, time consuming, and costly.

Large-scale data collection was carried out using a web-based survey based on methods of Dillman (2000). E-mail lists were purchased from The Council of Supply Chain Management (CSCMP), Rsateleservices.com, and Lead411.com. Seven SIC codes were covered in the study: 22 "Textile Mill products", 23 "Apparel and other Textile Products", 25 "Furniture and Fixtures", 34 "Fabricated Metal Products", 35 "Industrial Machinery and Equipment", 36 "Electrical and Electronic Equipment", and 37 "Transportation Equipment". The lists were limited to organizations with more than 100 employees, as they were most likely to participate in SCM initiatives. Since the focus of this study is SCM, the target respondents were the operations / manufacturing / purchasing / logistics / materials / supply chain – vice presidents, directors, and managers, as these personnel were deemed to have the best knowledge of the supply chain area. When answering the questionnaire, respondents were asked to refer to their major suppliers or customers. The final version of the questionnaire was given to 5498 target respondents by e-mail. The survey was sent by e-mail in three waves to ensure a reasonable response rate.

The response rate was calculated based on the number of clicks generated by the email and the total number converted to a completed survey. A total of 714 click-throughs were generated after three waves of emailing and 294 completes were obtained to provide a good response rate of 41.18%. Response rate based on click-throughs may be a better measure for email surveys since large amounts of emails sent in this way are treated as spam by the email program of respondent organizations and are unable to be retrieved or viewed by the target respondent. Since it is difficult to track this information accurately, a more appropriate measure would be to base the analysis on the number of people who visited the site and had the opportunity to review this study's request and purpose, and then decline to complete the survey on any number of grounds.

11% of the respondents are CEO/President, 45% are Vice Presidents, 25% are Directors, and 19% are Managers. Thus 81 percent of the respondents (CEOs, VPs and Directors) are high-level executives, implying a high level of reliability of the responses received, as these executives have a wider domain (job responsibility) and administrative knowledge. This is in line with previous survey-based SCM studies (ex: Frohlich and Westbrook, 2002). The areas of expertise included 11% executives (CEOs/Presidents), 12% purchasing, 22% SCM, 18% distribution/transportation/logistics, 20% manufacturing/production, 10% materials and 7% other categories such as sales. Thus, the domains of the respondents cover all key functions throughout the supply chain, from purchasing, manufacturing, sales and distribution. Since 33% of respondents have been with the organization for more than 10 years and 21% have been with their organization for 6-10 years, the majority of respondents have a comprehensive view of the supply chain program of their company.

This research did not directly investigate non-response bias, as the email lists only had individual names and email addresses without the organizational details. This research compares those subjects who responded to the first e-mail wave and those who responded to the second/third wave. The succeeding waves of the survey were considered representative of non-respondents (Lambert & Harrington, 1990; Armstrong & Overton, 1977). In previous SCM empirical research, similar methodology was also used (Li et al., 2005; Chen & Paulraj, 2004; Handfield & Bechtel, 2002). The comparisons were made using Chi-square tests ($\chi 2$ statistic). There was no significant difference between these two groups in the type of industry (based on SIC), the employment size, and the job title of the respondent (i.e. $p > 0.1$, when testing the null hypotheses: there is no significant difference in the distribution of responses across SIC codes/employment size/job title between groups). In addition, Chi-square independence tests were also carried out to determine whether the distribution of responses across SIC codes, employment size, and job title of the respondent is independent of the three waves when independently considered. No significant difference was found in industry type (based on SIC), employment size, or respondent's job title between the three groups / waves.

4 RESULTS

Thatte et al. (2013) found SCM practices to have a direct positive impact on SCR of a firm and confirmed the assertion in literature that organizations engaged in collaborative practices with their supply partners can better respond to customer demand. In order to explore the specific dimensions of SCM practices that lead to higher levels of SCR in terms of OSR, LPR, and SNR, a dimension-level statistical analysis was performed by employing stepwise regression analysis.

The stepwise multiple regression analysis is frequently used in exploratory studies (Aron and Aron, 1999). The individual dimensions of SCMP are predictors and the study seeks to understand which of these dimensions contribute significantly to the overall SCR prediction. A stepwise regression analysis is performed to determine which dimensions of SCM practices (viz. SSP, CR, and IS) are significant predictors of SCR (composite score). Results indicate an overall model of the three dimensions of SCMP that reasonably predict SCR, $R^2 = 0.194$, $R^2_{adj} = 0.186$, $F(3,290) = 23.271$, $p < 0.001$. The model accounted for 18.6% (R^2_{adj}) of the variance in SCR. A summary of regression coefficients indicates the three dimensions of SCMP in the order IS ($\beta = 0.223$), SSP ($\beta = 0.203$), and CR ($\beta = 0.128$) that significantly predict SCR.

By using stepwise regression analyses between SCMP dimensions IS, SSP, and CR as IVs and SCR dimensions OSR, LPR, and SNR as DVs, the study further examines which dimensions of SCMP significantly predict one or more dimensions of SCR.

Results indicate that only two dimensions of SCMP, in the order CR ($\beta = 0.227$) and SSP ($\beta = 0.180$), significantly predict OSR. Results suggest that IS does not contribute significantly to the prediction of OSR.

The results are not significant ($R^2_{adj} = 0.090$) to draw conclusions with regards to LPR. It is desired that R^2_{adj} be at least 0.10 to indicate that the given IV explains at least 10% of the variance in DV, so as to draw any substantial inferences (Mertler & Vannatta, 2002). The results indicate that none of the SCMP dimensions predict the LPR dimension of SCR when considered individually.

Results show that only two dimensions of SCMP in the order SSP ($\beta = 0.242$) and IS ($\beta = 0.216$), significantly predict SNR. As observed, CR does not contribute significantly to the prediction of SNR.

Construct-level regression analysis results found direct and positive impact of SCMP on SCR, and support the structural equation modeling results between SCMP and SCR found by Thatte et al. (2013). The dimension-level regression analyses results suggest that IS, SSP, and CR, in that order, can improve SCR. Results suggest that CR and SSP, in that order, can contribute in improving OSR, while SSP and IS can improve SNR. The study did not find support for the impact of SCMP dimensions on LPR. This could be attributed partly, to the distribution of the variance explained by the IV on the DV when dimension level analyses are performed, thus leading to the reduced significance of these dimension level analyses. These findings are discussed in the following section.

5 RESEARCH FINDINGS AND IMPLICATIONS

This study provides researchers an insight about the specific SCM practice dimensions that positively impact SCR of a firm. SCMP was found to reasonably predict SCR of a firm, supporting the findings of Thatte et al. (2013). The study found that information sharing and effective relationships with customers and suppliers can directly lead to higher levels of SCR. In addition, effective relationships with customers and suppliers will positively influence a firm's ability to be operationally responsive to demand changes by customers. This result suggests that organizations must select suppliers based on the potential for close long-term relationships. The study did not find IS to improve OSR. The study also did not find CR to improve SNR. Furthermore, the study found that none of the dimensions of SCMP significantly predict LPR.

For managers and organizations, the findings imply that organizations that are involved in IS practices are instrumental in achieving a SCR. Also, organizations that are engaged in SSP initiatives wherein organizations set goals and targets and plan and solve problems jointly with suppliers to meet such targets, select suppliers based on quality, include suppliers in continuous improvement programs, and involve key suppliers in new product development initiatives, can achieve higher SCR. Additionally, firms that frequently interact with customers to set reliability, responsiveness, and other standards, regularly measure and evaluate customer satisfaction and determine future customer expectations, facilitate customers' ability to seek assistance from them, and periodically evaluate the importance of the relationship with their customers, can achieve higher levels of SCR.

The results found CR and SSP to predict OSR. This implies that having close customer and supplier relations develop a better understanding between trading partners and is instrumental in increasing a firm's ability to rapidly respond to demand changes by customer. The study finds that through CR and SSP practices organizations can be more operationally responsive in terms of being able to respond rapidly to changes in product volume demanded by customers, effectively expedite emergency customer orders, rapidly reconfigure equipment to address demand changes, rapidly reallocate people to address demand changes, and rapidly adjust capacity to address demand changes.

The study also found that firms' suppliers can be more responsive in terms of being able to change product mix in a short time, consistently accommodate the focal firm's requests, provide quick inbound logistics to the focal firm, and being able to effectively expedite the focal firm's emergency orders, by engaging in the aforementioned IS practices and SSP with the focal firm.

The findings of this research assure practitioners that SCM is an effective way of competing, and the implementation of SCM practices does have a strong impact on SCR. This study provides predominant SCM practices that directly impact SCR on an aggregate basis, as well as on one or more of its dimensions.

The findings imply that organizations may be able to improve their overall SCR through IS, SSP, and CR. Organizations can be operationally more responsive through collaborative, inclusive, and win-win relationship practices with upstream and downstream supply chain trading partners, in terms of the measures of CR and SSP. Also, firms' suppliers can be more responsive through strategic partnership practices in terms of the six measures of SSP, and two-way information sharing in terms of the measures of IS, with the focal firm downstream. The findings may encourage practitioners and firms to emphasize on these SCM practices to boost SCR, OSR, and SNR. It could be in the best interest of firms to improve their SCR, OSR, and SNR as these abilities have been found to improve firm competitive advantage (Thatte & Agrawal, 2017; Thatte et al., 2018). The study also provides a research framework that identifies positive and significant relationships between SCMP and SCR. It provides an insight for future research in the area of SCR and SCMP.

6 LIMITATIONS AND FUTURE RESEARCH

In this research, the revalidation of constructs was not performed due to the limited number of observations (294). In future research, this may to be addressed. To improve the response rate, new mailing lists and research methods can be used. Some measurement inaccuracy may be generated by using a single respondent. In order to enhance generalizability, future research may extend or replicate the study for other types of industry. Future research may also apply multiple methods of obtaining data. The use of single respondent to represent intra or inter-organization wide variables may generate some inaccuracy (Koufteros, 1995). Future research may seek to use multiple respondents from each participating organization to improve the reliability of the research findings. Future research may test the relationships in different countries identifying country-specific SCM issues. Because the study found no support for the impact of SCMP dimensions on LPR, future studies can further investigate this aspect.

In future studies, the effects of additional SCMP dimensions on SCR not studied in this research can be studied. Future research may study SCMP and SCR at the supply chain level. To find out how SCM practices differ by industry in improving SCR, investigating the different SCMP and SCR components across supply chains operating in different industries may be interesting. Future studies may perform item-level data analyses to identify which individual SCM practices boost different dimensions of SCR. Such studies would be useful in drawing additional practical and theoretical implications.

REFERENCES

References available upon request

Designing Automated Recirculating Aquaculture Control for Shrimp Farming

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Abstract: Shrimp farming in America is inefficient and expensive. As such, many improvements could be made on current technologies for indoor shrimp farming. In order to tap into this market, a year-round indoor shrimp farming system, Automated Recirculating Aquaculture Control System (ARACS), is developed to address this need. The system consists of a recirculating aquaculture system, controller, and a web server. The recirculating aquaculture system is used to ensure that water quality is kept at an appropriate level in order to maximize water reuse. All the important water parameters are measured via the ARACS controller. The controller also determines when the feeding motors are active. Lastly, the web server analyzes and graphically displays the data being sensed by the ARACS controller as well as allowing the user to alter the feeding schedule and calibrate sensors. This paper discusses the details of the system design of the ARACS system.

1 INTRODUCTION

There is steady increase in seafood consumption in U.S. in recent years (National Oceanic and Atmospheric Administration, 2019). According to USDA, shrimp is the number one seafood consumed in U.S., accounted for 27% of the total seafood consumption (Kantor, 2016).

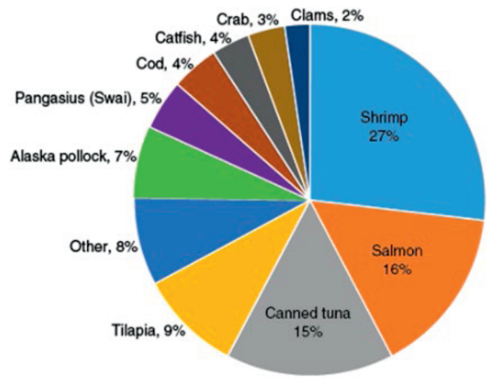

Figure 1. Seafood consumption in U.S.

Before the 1970s, the production of shrimp relied almost exclusively on the capture of wild shrimp. Due to the increase demand, more and more shrimp are produced in shrimp farms all over the world (Lavens, P. & Sorgeloos, P., 1996).

The total global production of fish and other aquatic animals reached 171 million tons in 2016. Of this total, capture production was 91 million tons and aquaculture production was 80 million tons. The top ten aquaculture producers were China (49.2 million tons), India (5.7 million tons), Indonesia (4.9 million tons), Viet Nam (3.6 million tons), Bangladesh (2.2 million tons), Egypt (1.4 million tons), Norway (1.3 million tons), Chile and Myanmar (1 million tons, respectively) and Thailand (0.96 million tons (FAO, 2016).

Current shrimp farming practices in American coastal climates produce on average 20,000 pounds of shrimp per acre of water each year, while tropical climates overseas can produce an average of 60,000 pounds per acre of water each year. As a result, 93% (over 560 tons) of America's shrimp supply is imported each year (Hickman *et al*, 2018). In addition to low farming yields, shrimping boats use large, indiscriminate nets which causes bycatch. This leads to thousands of pounds of non-shrimp aquatic wildlife being discarded like trash. As an example, more than 15% of shark species are on the brink of extinction because they are accidentally caught in purse seines, trawls, and longlines.

One can find many resources for developing shrimp farming products (Fujimura and Okamoto, 1972; Wheaton, 1977; Kungvankij *et al*, 1986; New 1987; Avnimelech *et al*, 1994; Tave, 1996; Johnson and Bueno, 2000; New 2002; Weaver, 2006); however, indoor shrimp farming in America is inefficient and not competitive. Indoor shrimp farming in U.S. has potential to become more competitive and grow significantly. The key is to use technologies for shrimp farming improvement. There are some commercial farming systems and smaller scale products such as the Mini Fish Farm by Pentair ($4k) and Fish Farm II by Pentair ($7K)(Pentair, 2019). These generic fish farming systems are expensive and may not have the specific features that can improve the efficiency and convenience for shrimp farming.

With the demand for shrimp on the rise, it is important to capture this untapped industry by developing competitive products in America to grow shrimp inland using available technologies.

The objective of this paper is to design an automated shrimp farming system, Automated Recirculating Aquaculture Control System (ARACS), using off-the-shelf components so that the cost is low, it is scalable and can be custom-designed.

2 SYSTEM DESIGN

ARACS will consist of a recirculating aquaculture system, sensors, controller, and a local web server. The recirculating aquaculture system is used to ensure that water quality is kept at an appropriate level in order to maximize water reuse. All important water parameters are measured via the ARACS sensors. The controller govern when the feeding motors are active. Lastly, the web server analyzes and graphically displays the data being sensed by the ARACS controller, and allows the user to alter the feeding schedule and calibrate sensors from the webpage.

2.1 System design requirements

The System design requirements of the ARACS are listed as follows:

- be wall powered (110VAC outlet, 15A, 60Hz);
- be Humidity resistant (up to 70% environmental humidity);
- sense temperature (range: 10 C – 50 C, accuracy: > 99% or error < 0.5 C);
- sense salinity (by measuring the conductivity of water; range: 0.1-30 mS/cm, accuracy: >95% or error <0.05 mS/cm);
- sense dissolved oxygen (range: 0-60 mg/L, error < 0.1 mg/L);
- sense pH level (range: 3-10, error < 0.01);
- send sensory data to a web server via WIFI (at least once per minute);
- analyze and display data on the webpage
- be able to control the feed management system;
- allow user to manually control the feed management system from the web page;
- allow user to calibrate and initialize sensors via web page;
- remove settleable solids (remove any suspendable solids greater than 100 microns in diameter);
- remove ammonia and nitrite;
- oxygenate the water in the tank;

2.2 System architecture

The ARACS system consists of recirculating tanks, pumps, sensors, controller, and web page. The recirculating system flow is illustrated in Fig. 2. The focus of this paper is on the design of sensor signal processing, controller, communication, and web page with user interface.

Shrimp growth is largely dependent on the levels of several parameters in the water. These water parameter levels include: temperature, salinity, dissolved oxygen, and pH. These parameters must be constantly monitored to maximize shrimp growth. Additionally, monitoring these parameters ensures that the ARACS is working properly.

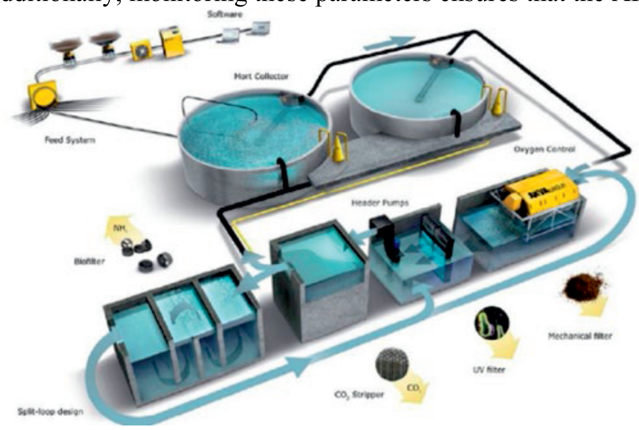

Figure 2. Recirculating Aquaculture System flow diagram

The conceptual block diagram for the ARACS controller is illustrated in Fig. 3.

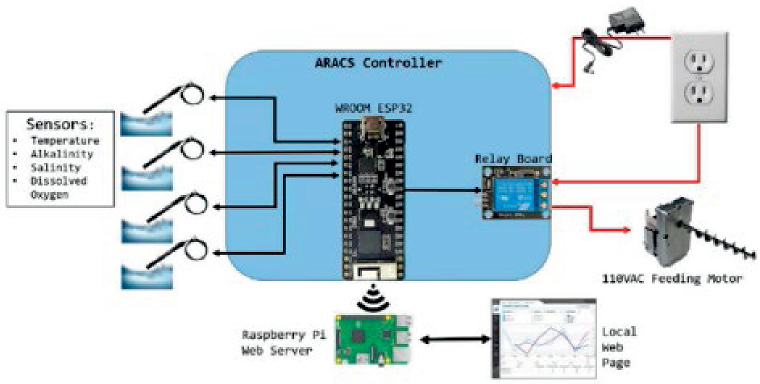

Figure 3. ARACS controller conceptual block diagram

The ARACS Controller will receive power via an AC/DC converter. This provides power for the sensor processing microcontroller, and the relay controlling the feed motor. The sensor processing microcontroller functions as the intelligence of our ARACS controller. It receives sensory data from the temperature, pH, salinity, and dissolved oxygen sensors. It also controls the feeding motor by turning the relay on and off. Additionally, there will be another 110VAC connection to the relay inside the ARACS controller. This 110VAC connection will be used to power the feeding motor whenever the sensor processing development board triggers the relay. The sensor processing microcontroller then communicates with a Raspberry Pi web server in order to display the sensory data on a local webpage. From the web page, control values can be set and communicated back to the sensor processing microcontroller to manage automated feeding. Additionally, the web page can be used to calibrate the probes.

In order to properly enclose all electronic components and prevent moisture from entering the system, ARACS utilizes o-ring seals to create a gasket to seal the contents of the enclosure from the humid outer environment. In the event that moisture does enter the enclosure, desiccant packages are used to absorb moisture on the interior of the enclosure.

Waste build up in the tanks will cause the water quality to drastically decline. Waste produced by the shrimp needs to be collected and filtered out. Shrimp that have died during the growing process can also cause this decline and water quality, reducing the system's overall performance. This build up of organic matter in the water will create a dense “cloudiness” of the water and heavily impact the growth of shrimp. A settling tank and protein skimmer is used to combat waste and other organic proliferation. Larger wastes will be collected with a settling tank while smaller wastes will be removed from the water with protein skimmers. The settling tank is the first component after the rearing tank; it is responsible for catching any suspendable solids greater than 100 microns in diameter. The flow of the water is heavily decreased so that any large solids can slowly sink to the bottom of the tank and later be discarded. Once the heavy solids have been collected, all other solids (less than 100 microns) are collected by a protein skimmer. The protein skimmer creates a torrent of air bubbles. The electrically charged protein molecules (light solids) attracted to the surface of these air bubbles are brought to the surface of the water as foam.

In order for the shrimp to live in a non-toxic environment, ammonia and nitrite must be removed from the recirculating aquaculture system with a biofilter. The biofilter is the last component in the process tasked with cleaning and filtering the water. A biofilter uses media with a large surface area that are covered in bacteria responsible of converting ammonia to nitrite and nitrite to nitrate.

Shrimp require oxygen to survive. If the water is not properly oxygenated, the shrimp, along with the bacteria in the biofilter, will cease to live. As shown below in Fig. 3, a Venturi Pump will be used to accomplish two main requirements for the system. First, it will oxygenate the water. Second, the pump will provide water flow. This is done by positioning the pump at the bottom edge of the tank so that it pulls water from the opposite end of the tank and pumps air into the other side. The air bubbles will rise to the top.

Figure 3. Venturi Pump for oxygenation

2.3 System components

A 5V DC Wall Wart is used to convert 110 VAC to 5VDC. A sensor processing development board, ESP-WROOM-32, was selected based on its low cost ($15), WIFI capability, and simplicity to use. The Atlas Scientific probes were chosen based on simplicity, price, and ease to calibrate. Atlas Scientific offers EZO boards which handle all conversion of readings from the probe, including amplification and noise isolation, as well as outputting I2C. With one board handling all operations needed to receive an I2C signal from the probe, it's simple for future redesigns to buy a new EZO board instead of ordering/soldering several integrated circuits. The EZO board offers an easy solution to calibrating each probe. Atlas Scientific offers a package which includes all components necessary for a full water monitoring kit. This includes all probes and EZO boards, calibration solutions, and BNC connectors. Instead of developing hardware/software that is individually modified for each probe, all hardware and software will be developed with one EZO board in mind. The following probes were selected: Dissolved Oxygen Probe ENV-40-D, Salinity Probe ENV-40-EC-K0.1,Temperature Probe PT-1000, Alkalinity Probe ENV-40-pH.

Raspberry Pi V3 is selected to host the local web server, utilizing an SQLite database to store all data retrieved from the ARACS controllers. The Raspberry Pi V3 supports SD cards up to 32GB in order to store a large amount of historical data. Flask, a python microframework, is used to create the web page. All of the sensory data can be viewed on the web page. The graphical representation is created using MatPlotLib. Depending on what the user chooses to see, MatPlotLib will pull the required information from the SQLite database and create graphs from it. Flask will then request these graphs and display them on the web page, as illustrated in Fig. 4.

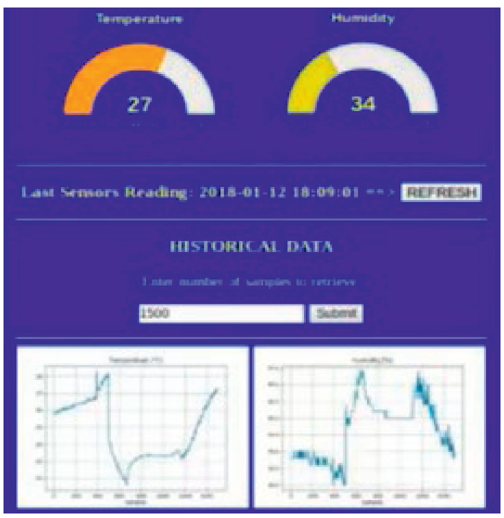

Figure 4. Display of sensory data on web page

As the parameters in the water are altered, so must the feeding schedule. Because the feeding schedule is so important in controlling the parameters of the water, it is also important that the user be able to change the frequency and amount of time that shrimp are fed. The web page will include options for the user to control when in a 24 hour period the motor is active, and how much food is to be dispensed at each active state. Once a setting is changed, the Raspberry Pi V3 will broadcast this change to the ESP32, the device controlling when the feeding motor is on or off.

Although the sensors are sturdy and require little maintenance, they will need to be recalibrated approximately once per year in order to obtain the most accurate results. The web page has several buttons that will initiate the calibration process for each probe. Once pressed, 'Cal' in an I2C ASCII bit stream will be sent to the EZO board of that probe, thus beginning calibration.

2.4. Circuitry design

Although many components in ARACS are off-the-shelf, a printed circuit board needs to be designed to integrate the components. A part of the circuit is illustrated in Fig. 5.

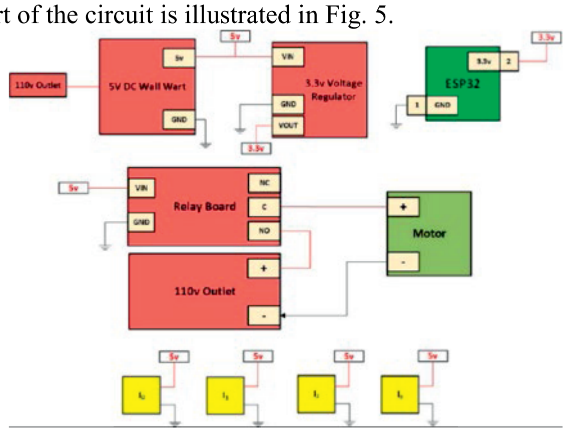

Figure 5. Printed circuit board design

Fig. 6 is a picture of the finished controller box.

Figure 6. ARACS controller: a finished prototype

3 TESTING

To validate the design requirements, system and component level tests were designed. A test matrix is illustrated in Table 1, which shows how each requirement is validated by at least one test.

	Wall powered	Humdity resistant	Multiple parameter sensing	Feed management control	Transmitting sensory data	Data analysis/display	Feed management via web page	Sensor calibration via web page	Remove settleable solids	Remove ammonia/Nitrite	Oxygenation
110V AC Test	X			X							X
5V DC Test			X	X							
3.3V DC Test			X		X						
Enclosure Moisture Test		X									
Wilreless Transmission Test					X		X	X			
Water Quality Measurement			X	X		X			X	X	X
Sensor calibration								X			
Data Display					X	X					

Table 1. Test matrix for requirement validation

4 COST ANALYSIS

One of the objectives of ARACS design is low cost. This is achieved by using competitive off-the-shelf components. The Atlas probes kit costs $879. The PCB fabrication and population cost $350. The ESP32 microcontroller costs $15. The Raspberry Pi 3 costs $35. The 5V DC wall wart costs $12. The total cost for the ARACS controller is $1291. When purchase in volume, the cost will be significantly lower.

5 CONCLUSIONS AND FUTURE WORK

A year-round indoor shrimp farming system, Automated Recirculating Aquaculture Control System (ARACS), was designed. The design process started with system requirements followed by system architecture design and component selection. A test matrix was created to validate the design requirements. By using off-the-shelf components, the cost of ARACS was kept low. A web page is designed to allow analyze and graphically display of sensor data collected by ARACS as well as allow the user to alter the feeding schedule and calibrate sensors.

Future work includes fabrication, integration, and test of the entire recirculating system, optimization, and scaling to industrial size.

REFERENCES

[1] L. Kantor, Americans' Seafood Consumption Below Recommendations, Amber Waves Magazine, 2016. Last accessed on July 24, 2019: https://www.ers.usda.gov/amber-waves/2016/october/americans-seafood-consumption-below-recommendations/

[2] National Oceanic and Atmospheric Administration, American seafood industry steadily increases its footprint, December, 2018. Last accessed on July 24, 2019: https://www.noaa.gov/media-release/american-seafood-industry-steadily-increases-its-footprint

[3] P. Lavens and P. Sorgeloos, eds. 1996. Manual on the production and use of live food for aquaculture. FAO Fisheries Technical Paper No. 361. Rome.

[4] A. Hickman, C. Pryor, M. Salidivar, F. Solorzano, and J. Brookins, System design process for Aquatech systems, TAMU capstone report, 2018.

[5] Pentair, The Mini Fish Farm, The Automated Fish Farm, Last accessed on July 24, 2019:

[6] https://pentairaes.com/the-mini-fish-farm.html; https://pentairaes.com/fish-tm-farm-automated.html

[7] P. Kungvankij, T.E. Chua, B.J. Pudadera, Jr. L.B. Tiro, Jr., G. Corre, I.O. Potestas, E. Borlongan, G. A. Taleon, Alava, and J. N. Paw , Shrimp culture: pond design, operation and management, NACA Training Manual Series No. 2, 1986.

[8] Food and Agriculture Organization (FAO) of the United Nations, Fishery and Aquaculture Statistics: Aquaculture Production, 2016 FAOYearbook, Rome.

[9] F.W. Wheaton, Aquacultural engineering, New York, John Wiley & Sons, 1977.

[10] D. E. Weaver, "Design and operations of fine media fluidized bed biofilters for meeting oligotrophic water requirements". Aquacultural Engineering. 34 (3): 303–310. 2006. doi:10.1016/j.aquaeng.2005.07.004.

[11] M. B. New, Farming Freshwater Prawns; FAO Fisheries Technical Paper 428, 2002. ISSN 0429-9345.

[12] Y. Avnimelech, M. Kochva, et al. "Development of controlled intensive aquaculture systems with a limited water exchange and adjusted carbon to nitrogen ratio". Israeli Journal of Aquaculture Bamidgeh. 46 (3): 119–131, 1994.

[13] Martins, C. I. M.; Eding, E. H.; Verdegem, M. C. J.; Heinsbroek, L. T. N.; Schneider, O.; Blancheton, J. P.; d'Orbcastel, E. R.; Verreth, J. A. J. (2010). "New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability" (PDF). Aquacultural Engineering. 43 (3): 83–93. doi:10.1016/j.aquaeng.2010.09.002

[14] D. Tave, Selective breeding programmes for medium-sized fish farms. FAO Fisheries Technical Paper No. 352. 1996, Rome.

[15] M.B. New, Feed and feeding of fish and shrimp - a manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. Report No. ADCP/REP/87/26. Rome, FAO. 1987.

[16] T. Fujimura and H. Okamoto, Notes on progress made in developing a mass culturing technique for Macrobrachium rosenbergii in Hawaii. In T.V.R. Pillay, ed. Coastal aquaculture in the Indo-Pacific region, pp. 313-327. West Byfleet, England, Fishing News Books, 1972.

[17] S.K. Johnson and S.L.S. Bueno, Health management. In M.B. New & W.C. Valenti, eds. Freshwater prawn culture: the farming of Macrobrachium rosenbergii, pp. 239-258. Oxford, England, Blackwell Science, 2000.

Repeatability and Reproducibility Study of an Articulated Arm Coordinate Measuring Machine

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Abstract: This paper represents a study aimed at evaluating the repeatability and reproducibility of an articulated arm coordinate measuring machine (AACMM) used for setup approval and final part inspection by a local manufacturer. While periodic calibration data are available, there is a growing interest in quantifying the inherent precision of the arm when used by different inspectors. Two methods for performing the study were considered. One following the procedure recommended by the Automotive Industry Action Group (AIAG) and another recommended by Wheeler (2006). Statistical analysis of the results indicated the class of the arm and did not support its suitability for the intended application.

1 INTRODUCTION

Articulated Arm Coordinate Measuring Machines (AACMMs) are widely being used in the manufacturing domain specifically in the industries that need highly reliable products with accurate and precise measurements. Considering the high importance of such measurements, it is essential to analyze the performance of the AACMMs. Previous studies considered factors that tend to affect the uncertainty of the measurements and methods to control them. Statistical methods are commonly used for this purpose.

Shimojima et al (2003) performed a study on an AACMM to find the best method for estimating the uncertainty associated with the measurements. They have concluded that traceability of AACMM is hard as the calibration is performed by the manufacturers. For this purpose, they use a 3D artifact with 9 balls on a plate (3DBP or 3D ball plate) for calibration. They put these balls in 5 different locations and orientations to measure 45 points in total using a cone-shaped stylus in an A-CMM. They determined the parameters in each location and orientation and applied each set of kinematical parameters to the five different situations for the measured points. Based on the root mean square calculations for 25 different combinations, they observed better results than the originally specified accuracy. González et al (2012) developed a real-time force measuring system and implemented it for an AACMM. The forces that operators cause while collecting the measurements were measured using that strain gauges. To assess if the operator contact forces influenced AACMM performance, they carried out a measuring contact force characterization study. They concluded that the force level and its variability changes dramatically in different repetitions for different operators. Therefore, they proposed additional studies for a solution to these sources of errors.

Gonzales et al (2014) expanded their study to identify the influence of human factors on the performance of AACMM. They mentioned that based on the main principles of metrology instrument calibration and reproducing measurements should occur in the same environment with the same instrument handling and parameters to get suitable information. However, these facts are neglected in AACMM calibration. Instead of performing in-situ calibration, AACMM calibration is performed in the manufacturer's facility and as a result, the accuracy and reliability of measurements tend to be different during industrial operations of the machine. They presented a new methodology for evaluating the performance of the operators and the AACMM. The main parameters in their study are operator, contact force and type of feature. They used the ANOVA procedure to analyze the effects of these parameters and their influence on the AACMM performance. They reported that the stated factors have a significant effect on the uncertainty of the measurements. They concluded that the probe bending force is the most relevant and suggested replacing the stiff probes by probes capable of recording force readings. They also concluded that geometric features do not have significant effects on measurements although each feature needs its measurement technique.

While some studies on AACMM have used ANOVA and other statistical methods for their analyses, repeatability, and reproducibility (R&R) analysis received limited attention. Barrentine (2003) stated that in operating a gage, the overall variation is attributed to product variation and the measurement system variation. Therefore, to obtain the total variability it is necessary to identify components of gage variation and quantify them. Gage variability itself is made of two components. The first one is repeatability or equipment variation, which is the variation due to repeated measurements by a single operator on the same part. The second component is reproducibility or appraiser variation, which corresponds to the variation due to measurements by different operators using the same gage. Generally, a gage R&R study considers two or more operators, one gage, and up to ten parts for measurement. Each operator will measure each part two or three times, resulting in a fully-crossed data structure with subgroups of two or three measurements (Wheeler 2009). The mathematical equivalent of these components is given by:

$$\sigma_{total}^2 = \sigma_{product}^2 + \sigma_{gage}^2$$
$$\sigma_{gage}^2 = \sigma_{repeatability}^2 + \sigma_{reproducibility}^2$$

Different methods are utilized in quantifying these components. Montgomery & Runger (1993) presented various designs for evaluating the gage repeatability and reproducibility. In their work, the classical estimates of variance components were replaced by modified estimates. They obtained point estimates and confidence intervals for estimating each component. The Automotive Industry Action Group AIAG (2002) identified three different methods and stated the limitations for the existing methods (Ermer 2006). The first is the average range method, which is a quick approximation method and does not decompose variability into repeatability and reproducibility. The second method involves the use of control charts. This is a good method that plots control charts to identify special causes. However, this method does not address possible interactions between different factors in the experiment. The third method utilizes an analysis of variance (ANOVA) procedures and tests the hypotheses regarding possible interactions. To mitigate the mathematical complexity of these methods, AIAG suggested another procedure which is made of several steps and uses simple calculations. This method has been widely used for several years especially in the automotive industry.

Antony, Knowles, and Roberts (1999) compared the gage capability analysis of the classical method and the ANOVA method. They used a case study to investigate the advantages of ANOVA, which resulted in detecting the interaction between parts and operators. As a result, the ANOVA approach was strongly recommended over the classical methods.

Although the AIAG procedure is being used since 1990, it has been modified during the past years and revised editions are released each year. However, as Wheeler stated in his study in 2006, it still has a major problem that has not been addressed yet. Wheeler (2009) explained the faults of AIAG method and proposed a new method called "Honest Gauge R&R".

In the following section, we present a study involving a portable coordinate measuring machine (AACMM) utilized by a local manufacturer for setup approval and final part inspection. Section 2 demonstrates the experimental setup and the steps followed for data collection. Section 3 provides the data analysis using both the AIAG method and wheeler's honest gage R&R. Section 5 provides concluding remarks with suggestions for future works.

2 EXPERIMENTAL SETUP

The first step in our study is the selection of experimental design to perform the R&R study. The setup consists of 7 identical parts, 3 operators and 3 trials for each. The measurement device used in this experiment is an AACMM with a measuring range of 13 ft., and volume length accuracy of 0.003 in. Calibration is performed using special software which records the measurements and reports the results. Perpendicularity concerning the datum surface A, key requirement #10 as shown in Figure 1, was measured three times by each operator. The experimental setup and measurement locations are shown in Figure 2.

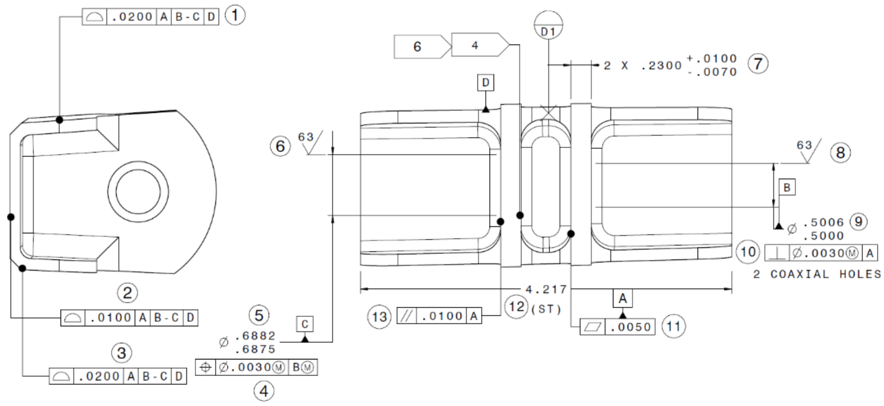


Figure 1. Part design

Figure 2. Setup design

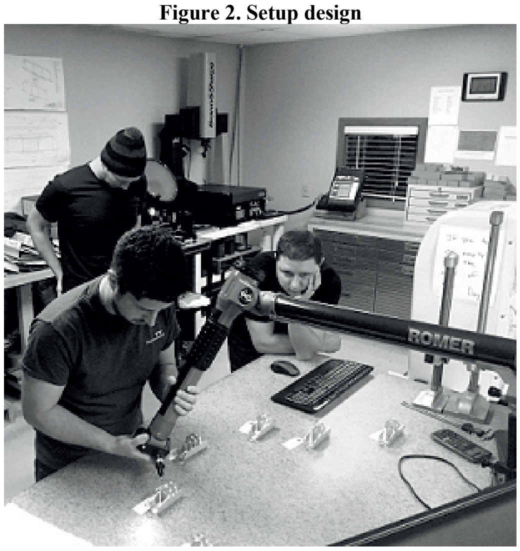


Figure 3. Three trained operators collecting the measurements

The arm is fixed to the granite measurement surface and the parts are located at random to 7 different locations around the arm as shown in Figure 2. Operators were assigned parts in a completely randomized order (Figure 3). As all the measurements were made in the measurement laboratory within the same day, environmental factors were ignored. A total of 63 measurements were collected and analyzed using both AIAG and Wheeler's methods. The data is shown in Table 1.

3 DATA ANALYSIS

In this section, we use two methods of gage R&R study i.e. AIAG and Wheeler's method to analyze the collected data. The first method, presented by AIAG, decomposes variability to equipment variation (EV), appraiser or operator variation (AV), and part or process variations (PV). These components are represented and defined in Table 2. Let n, o, and p represent the number of trials, the number of operators and number of parts respectively. Thus, in this study n =3, o =3 and p =7. According to the AIAG method, gage variability and total variability were obtained as:

$$GRR = \hat{\sigma}_e = \sqrt{EV^2 + AV^2}$$
$$TV = \hat{\sigma}_x = \sqrt{EV^2 + AV^2 + PV^2}$$

The results obtained are shown in Table 3.

As was noted by Wheeler (2006), the total variability in the AIAG method is indeed more than the sum of its components. As can be seen in Table 3, the sum of the percentages is higher than the total variability. Wheeler (2006 and 2009) presented a detailed discussion of this problem and proposed a 14-step methodology for conducting R&R studies.

Also, the last column in Table 3 represents gauge classifications as suggested by AIAG (2002). Values of CR = $\sqrt{2}$ σp/ σe less than 10% are considered good. These values are used to define the relative utility of the gage with the ranges defined in Table 4.

Table 1. Perpendicularity measurements on 7 parts by 3 operators

Part	1	2	3	4	5	6	7
Operator 1							
Trial 1	0.001639	0.001474	0.001035	0.002175	0.001494	0.00177	0.001857
Trial 2	0.001561	0.001466	0.001518	0.001646	0.001784	0.001801	0.002845
Trial 3	0.001544	0.001445	0.001084	0.001008	0.001539	0.001476	0.00163
Operator 2							
Trial 1	0.004325	0.001798	0.004193	0.003122	0.002984	0.002872	0.003014
Trial 2	0.002412	0.001996	0.002083	0.002763	0.002826	0.002389	0.002688
Trial 3	0.00296	0.001691	0.002054	0.002285	0.002116	0.002289	0.002972
Operator 3							
Trial 1	0.00061	0.002078	0.000898	0.00249	0.002424	0.002219	0.001935
Trial 2	0.001097	0.000428	0.000594	0.002418	0.000954	0.001974	0.000778
Trial 3	0.001847	0.001998	0.001636	0.002131	0.000806	0.002815	0.000243

Table2. R&R Metrics for Sources of Measurement Error

$EV = \hat{\sigma}_{pe} = \frac{\bar{R}}{d_2}$	$\bar{R}$ is the average range for 21 subgroups of size n=3, d_2 is the Bias Correction Factor and $\hat{\sigma}_{pe}$ is the standard deviation for measurement error or repeatability
$AV = \hat{\sigma}_o = \sqrt{\left[\frac{R_o}{d_2^*}\right]^2 - \frac{o}{nop}\hat{\sigma}_{pe}^2}$	R_o is the range of operator averages, d_2* denotes Bias Correction Factor for estimating variances and $\hat{\sigma}_o$ is a deviation for appraiser error or reproducibility; o: number of operators, n: number of trials, p: number of parts
$PV = \hat{\sigma}_p = \frac{R_p}{d_2^*}$	R_p is the range of part averages and $\hat{\sigma}_p$ represents the deviation for part errors

Table 3. Summary of calculations using AIAG R&R

Source	Variance Estimates	variability	Proportion of Total Variation	Decision
Repeatability (EV)	2.860187E-07	5.348072E-04	0.66	Unacceptable
Reproducibility (AV)	3.298863E-07	5.743573E-04	0.77	Unacceptable
Combined R&R (GRR)	6.159050E-07	7.847962E-04	0.96	Unacceptable
Product Variation (PV)	4.955755E-08	2.226153E-04	0.27	Marginal
Total Variation (TV)	6.65463E-07	8.157589E-04	1.23	Unacceptable

Table 4: relative utility of the gage AIAG (2002)

% of Total Variation	Criteria
< 10%	Good
10% - 30%	Marginal
> 30%	Unacceptable

The same data set was analyzed following Wheeler's 14-step procedure. These steps are described below.

Step 1:

The average range of $K = o.p = 21$ was calculated as $\bar{R}$ = 0.000905429. Based on the subgroup size of n=3, a control limit factor of D_4 = 2.574 was used. This resulted in an upper limit for the ranges of $D_4\bar{R}$ = 0.002330573. None of the ranges exceeded the value of this upper limit.

Step 2:

The repeatability variance was obtained as $\hat{\sigma}_{pe}^2 = \left[\frac{\bar{R}}{d_2}\right]^2$ = 2.86019E-07. This is based on a bias correction constant d_2 = 1.693.

Step 3:

Using the range of the 3 operator averages, the reproducibility variance is estimated as:

$$\hat{\sigma}_o^2 = \left[\frac{R_o}{d_2^*}\right]^2 - \frac{o}{nop}\hat{\sigma}_{pe}^2 = 3.29886\text{E-}07$$

Step 4:

The combined R&R variance, which is the sum of values from steps 2 and 3, is calculated as:

$$\hat{\sigma}_e^2 = \hat{\sigma}_{pe}^2 + \hat{\sigma}_o^2 = 6.15905\text{E-}07$$

Step 5:
The range of part averages (R_p) is used to estimate the product variance as:

$$\hat{\sigma}_p^2 = \left[\frac{R_p}{d_2^*}\right]^2 = 4.95576\text{E}-08$$

Where d_2^*=2.827 and R_p= 0.000629333.

Step 6:
The value of the total variance $\sigma\hat{}_x{}^2$ = 6.65463E-07 is the sum of the results from steps 4 and 5. Steps 7, 8, and 9 compute the relative proportion of various factors as follows.

Step 7:
The proportion of the total variance that is consumed by repeatability is:

Repeatability Proportion = $\sigma\hat{}_{pe}{}^2/\ \sigma\hat{}_x{}^2$= 0.429804386

Step 8:
The proportion of the total variance that is consumed by reproducibility is:
Reproducibility Proportion = $\sigma\hat{}_0{}^2/\ \sigma\hat{}_x{}^2$= 0.495724779

Step 9:
The proportion of the total variance that is consumed by the combined Repeatability and Reproducibility is:
Combined R&R Proportion = $\sigma\hat{}_e{}^2/\ \sigma\hat{}_x{}^2$= 0.925529165

Step 10:
The proportion of the total variance that is consumed by product variation is an estimate of the intraclass correlation coefficient which is given by:

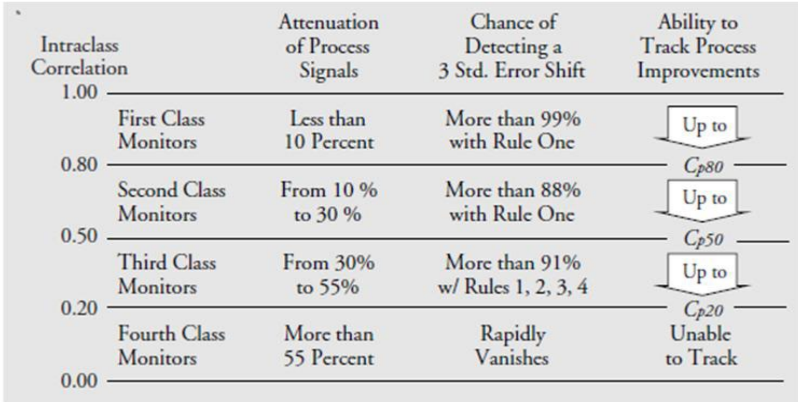
$$r_0 = \frac{\hat{\sigma}_p^2}{\hat{\sigma}_x^2} = 0.074470835$$

These results are summarized in Table 5. As can be seen, the proportions correctly add up to 1.

Table 5. Summary of the calculations of Wheeler's method

Source	Variance Estimates	Proportions
Repeatability	2.860187E-07	0.42980
Reproducibility	3.298863E-07	0.49572
Combined R&R	6.159050E-07	0.92553
Product Variation	4.955755E-08	0.07447
Total Variation	6.65463E-07	1

The last four steps in Wheeler's methodology are related to interpreting the results. Four classes of process monitors are defined based on the intraclass correlation statistic as shown in Figure 4. Using this classification, the AACMM considered here was classified as a fourth class monitors, since the attenuation of process signals defined by 1-r00.5 is 72.71 percent.



$$C_{p80} = \frac{USL - LSL}{6\,\sigma_{pe}}\sqrt{1-.80} \qquad C_{p50} = \frac{USL - LSL}{6\,\sigma_{pe}}\sqrt{1-.50} \qquad C_{p20} = \frac{USL - LSL}{6\,\sigma_{pe}}\sqrt{1-.20}$$

Figure 4. Four Classes of Process Monitors (Wheeler 2009)

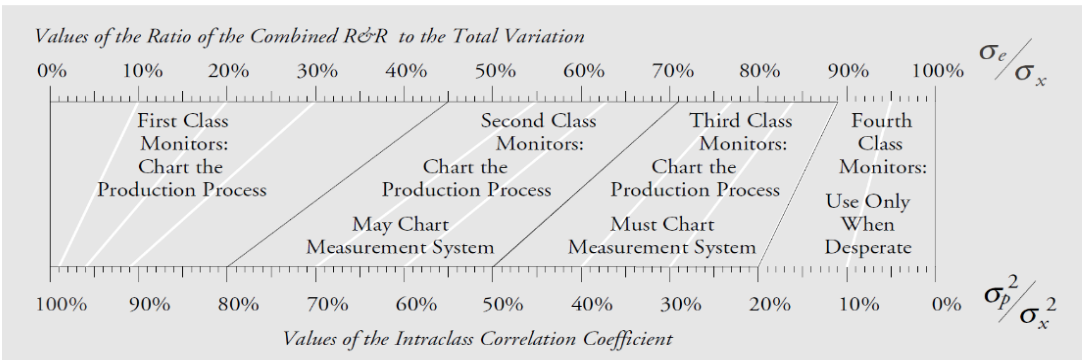


Figure 5. Identifying the class of the gage using AIAG and Wheeler's method

As mentioned earlier, the AACMM was classified as unacceptable based on the AIAG criteria, and as a fourth class monitor based on Wheeler's criteria. Wheeler (2009) represented both classifications on a single chart shown in Figure 5. The top axis represents the percentages used by the AIAG and the bottom axis represents those used by Wheeler. This chart suggests using a fourth-class gage only when there is no other option available.

4 CONCLUSIONS

This study represented repeatability and reproducibility analysis of an AACMM using two different methodologies. The study confirms that the components of variation by AIAG method do not add up to the total variation and AIAG method tends to over-estimate variability. Wheeler's method instead provides a more realistic assessment of the measurement system. The arm used to perform the experience in this study was classified as a fourth-class monitor. Based on Wheeler's guidelines, the AACMM is not appropriate for evaluating perpendicularity. These authors are investigating the performance of the same AACMM when used to measure other geometric features such as parallelism, flatness, and concentricity.

DISCLAIMER

Certain commercial systems are identified in this paper. Such identification does not imply recommendation or endorsement, nor does it imply that the products identified are necessarily the best available for the purpose. Further, any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors.

REFERENCES

[1] Antony, J., Knowles, G., and Roberts, P. (1999). Gauge capability analysis: classical versus ANOVA. *Quality assurance*, 6(3), 173-181.

[2] Barrentine, L. B. (2003). Concepts for R&R studies. ASQ Quality Press.

[3] Daniel, G. M., Joaquín, B., Eduardo, C., and Susana, M. P. (2014). Influence of the human factor in the AACMM performance: a new evaluation methodology. *International journal of precision engineering and manufacturing*, *15*(7), 1283-1291.

[4] Ermer, D. S. (2006). Improved gage R&R measurement studies. *Quality Progress*, 39(3), 77-79.

[5] González Madruga, D., Cuesta González, E., Barreiro García, J., Martínez Pellitero, S., and Álvarez Álvarez, B. J. (2012). Real-time contact force measurement system for portable coordinate measuring arms. In Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium, 23 (1). DAAAM International.

[6] González Madrugaa, D., Barreiro, j., Cuestab, E, Gonzáleza, B., and Martínez-Pelliteroa, S. (2014). AACMM Performance Test: Influence of Human Factor and Geometric Features. Procedia Engineering 69, 442 – 448

[7] Montgomery, D. C., and Runger, G. C. (1993) Gauge Capability and Designed Experiments. Part, 1, 115-135.

[8] Shimojima, K., Furutani, R., Takamasu, K., and Araki, K. (2002). The estimation method of uncertainty of articulated coordinate measuring machine. In *Industrial Technology, 2002. IEEE ICIT'02. 2002 IEEE International Conference* Vol. 1, pp. 411-415.

[9] Wheeler, D. J. (2009). “An honest gauge R&R study,” in Proceedings of the 2006 ASQ/ASA Fall Technical Conference (SPC Press, 2009), manuscript no. 189

[10] Wheeler, D. J. (2006). EMP (evaluating the measurement process) III: using imperfect data. *SPC, Knoxville, TN, Statistical Process Control Press*.

Deep Space Surveillance Radar Value Modelling

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Abstract: Value Driven Design has become increasingly popular in the Aerospace community. Value Driven Design is an approach to systems engineering that involves developing a Value Model to guide engineering design and decision making. Value Driven Design involves defining a system by a set of key attributes. A Value Model is a function of these attributes that models the preference of an entity. The Value Model evaluates a combination of the attributes and produces a numeric value that reflects the preference of an entity. That is, if two combinations of attributes were inputted The Value Model would output numeric values that are consistent with the preferences of an entity. Value measures the relative preference between one design and another. The Value Model could reflect the preferences of the designer, user of the design or any other relevant entity.

The purpose of this paper is to develop a Value Model for deep space surveillance radar systems, then demonstrate how that Value Model can be used for trade studies and optimization. Several relevant design attributes will be included and a Value Model will be derived. A technique for optimization will be developed and the deep space radar Value Model will be optimized. The Value Model will then be used to assess multiple designs of notional radar systems. The results of the Value Driven Design approach will be analyzed and discussed.

1 INTRODUCTION

Large ground based, phased array radars are highly complex systems with several competing performance parameters. Multi-pulse processing radars for Deep Space surveillance are a subset of this class of radar system. Modifications that occur on Deep Space surveillance radars are often performed using a set of requirements—that is, a point estimate of the combination of design parameters that define the system performance. It has been shown that this technique of requirements engineering frequently leads to suboptimal design (Collopy, 2007). An alternative approach is to create a Value Model for the radar system that can be provided in place of requirements (Collopy, 2001).

2 VALUE MODELING

The purpose of creating a Value Model for this system is to facilitate the direct comparison of alternative design concepts or implementations by deriving the relationship between the radar performance measures in the generation of a single metric. The creation of this single metric, where smaller values are always preferred, creates an Objective Function that can be evaluated to perform trade studies and design activities. Either traditional optimization techniques can be applied, or the model can be linearized and distributed as proposed by Collopy (2001).

2.1 Deep Space Surveillance Radar

Deep Space (DS) surveillance radars detect, track and identify Earth-orbiting satellites and debris in the DS orbital regime. The DS orbital regime is defined as having an orbital period greater than 225 minutes. DS surveillance radars support the Space Surveillance Network (SSN) by collecting smoothed radar measurements of the satellite—called Observations (Obs)—and sending those smoothed measurements to the Joint Space Operations Center (JSpOC). The JSpOC uses radar Obs to update the Orbital Element Set (ELSET) used to predict the location of the satellite at a time in the future. This prediction information is used to perform assessments such as conjunction analysis (Stuckey, 2011).

Since Obs are the primary data product produced by DS surveillance radars, a more efficient and effective radar can produce more Obs of a given quality in a given time. Ob quality is typically associated with measurement precision. Other factors that would impact the time required to collect Obs is availability, radar sensitivity, search volume and data processing time.

The metric used for the DS surveillance radar Value Model is shown in Equation (1).

$$Value = \frac{t}{O} \tag{1}$$

Where: O = Number of Radar Observations
t = time in seconds

Several key radar parameters impact the *Time Between Obs* metric that will be discussed, analyzed and added to the value model in the following sections.

2.2 The Radar Operation Modes Sequence

Virtually all radars, including DS Surveillance radars, follow a three-step sequence of operational modes to perform a radar track. This sequence is to perform Search, Verification and Track modes. That is, the radar begins by entering a Search mode where it generates large search volumes using course radar waveforms and searches for the target using a raster, bow-tie, spiral or some other type of scan. Once a search dwell indicates a target is detected, the radar will switch to a verification mode where it follows up on the search detection with a low Probability of False Alarm (Type I error). If the detection processing on the confirmation dwell indicates a target is present, then the target has been verified and the radar will initiate a track sequence. The track sequence involves collecting a sequence of measurements on the target and predicting the target state vector using a track filter. The sequence of measurements is smoothed to generate Obs to be sent to JSpOC. Most often, the radar collects three Obs for each successful satellite track.

The time to collect Obs is the sum of the time required to perform each of the three radar modes in the sequence. Therefore, for a successful collection, three observations are generated. This is shown in Equation (2).

$$t_{collection} = t_{acquisition} + t_{verification} + t_{track} \tag{2}$$

Where: $t_{collection}$ = total data collection time for DS (sec)
$t_{acquisition}$ = time required for target search function (sec)
$t_{verification}$ = time required for target verification (sec)
t_{track} = time required for target track function (sec)

2.3 The Radar Range Equation

The Radar Range Equation (RRE) is used to calculate the expected Signal-to-Noise Ratio (SNR) as a function of the parameters of the radar and the characteristics of the target. The SNR is the ratio of the power received from the target to the noise power. The basic radar range equation (Curry, 2005) is shown in Equation (3).

$$\mathrm{SNR} = \frac{\mathrm{P_t G_t G_r \lambda^2 \sigma n}}{(4\pi)^3 \mathrm{kT_0 BFL_S L_{Scan} R^4}} \tag{3}$$

Where:

SNR = Signal-to-Noise Ratio
P_t = Peak Transmit Power (Watts)
G_t = Transmitter Antenna Gain
G_r = Receiver Antenna Gain
λ = transmitted signal center wavelength (m)
σ = target radar-cross section (m2)
n = number of pulses coherently integrated
k = Boltzmann's constant (m2kgs-2K-1)
T_0 = System Noise Temperature (290 K)
B = Noise Bandwidth (Hz)
F = Noise Factor
L_s = System Losses
L_{scan} = Array Scan Losses
R = Target Range (meters)

The terms in Equation (3) can be grouped differently as shown in Equation (4).

$$SNR = \left[\frac{P_t G_t G_r \lambda^2}{(4\pi)^3 k T_0 BFL_S}\right]\left[\frac{\sigma n}{L_{Scan} R^4}\right] \tag{4}$$

The terms in the right bracket are dependent on the target RCS and geometry relative to the radar. The terms in the left bracket are internal to the radar and remain unchanged for a given waveform and center frequency. These radar specific terms are referred to as Loop Gain (ψ) and the radar range equation can be rewritten as shown in Equation (5).

$$SNR = \psi \left[\frac{\sigma n}{L_{Scan} R^4}\right] \tag{5}$$

Solving for the number of pulses required in the dwell yields Equation (6).

$$n = \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \tag{6}$$

2.4 Radar Dwell Time

For a DS radar, coherent integration is required, and the time required to perform coherent dwells and process the data in order to achieve sufficient SNR for detection. The time required to transmit and receive n pulses is equal to Equation (7).

$$t_{Dwell} = n \cdot PRI = \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI \tag{7}$$

Where:

t_{Dwell} = time required for a coherent dwell (sec)
PRI = Pulse Repetition Interval (sec)

The *ceil* function is used in Equation (7) because the number of pulses must be an integer and the computation of n is defined as the "minimum number of pulses for a given SNR". Therefore, t_{Dwell} is the time required to collect the required coherent data for a single radar measurement. There is time required to process the data, perform detection and schedule the next dwell. This time is added to Equation (7) to compute the total time for a single radar measurement. This is shown in Equation (8).

$$t_{Measure} = t_{Dwell} + t_{Process} = \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI + t_{Process} \quad (8)$$

Where: $t_{Measure}$ = time required to perform a single coherent radar measurement (sec)

$t_{Process}$ = time required for signal and detection processing of a coherent dwell (sec)

2.5 Radar Search Function

Fundamentally, the time required to perform radar search ($t_{acquisition}$) is the product of time required to process a single radar measurement ($t_{Measure}$) and the number of search dwells (measurements) required to acquire the satellite. For a given search volume, the radar can search the area using a number of dwells based on search volume, beam packing (how the beams are spaced), probability of detection and probability of false alarm.

The most basic model for the angular acquisition search volume is to divide the search extent in each dimension by the 3 dB beamwidth in the corresponding dimension. The equation for the number of angular search positions is shown in Equation (9).

$$n_{Angular} = \left\lceil \frac{\Delta U}{\delta u} \right\rceil \left\lceil \frac{\Delta V}{\delta v} \right\rceil \quad (9)$$

Where: $n_{Angular}$ = total number of required beams to cover angular area

δu = 3dB beamwidth in u dimension (sine space)

δv = 3dB beamwidth in v dimension (sine space)

ΔU = Angular Extent in U to be searched (sine space)

ΔV = Angular Extent in V to be searched (sine space)

The ceil functions are included to ensure an integer number of beam positions to cover the angular search area. The angular search area is shown in Figure 1.

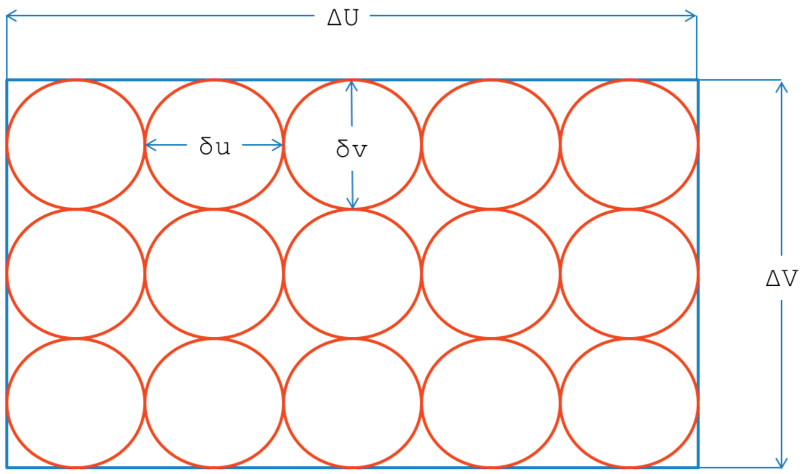

Figure 3. Angular Search Beam Pattern

Similarly, the number of dwells at each angular beam position is the ratio of the required search range extent divided by the width of an individual radar receive window. Therefore, if a single receive window is smaller than the required range search extent, the entire angular search volume will be repeated and stacked (in range) to cover the required search volume. As an example, the four-beam pattern is stacked to cover a larger range extent in Figure 2.

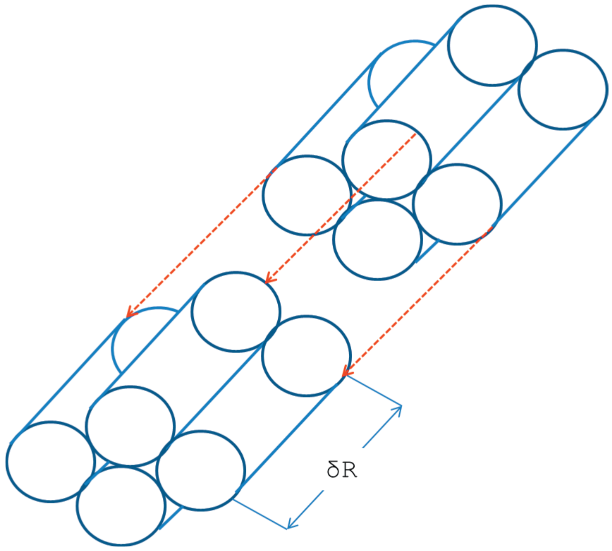

Figure 4. Beam Stack to Cover Range Extent

Therefore, the total number of beams required for the acquisition search function is the number of angular beam positions multiplied by the total number of required range stacked receive windows. To adjust for the potential overlap or packing factor in each dimension, an efficiency term is included. The final equation is shown in Equation (10)

$$n_{SerchDwells} = \left\{ e_{volume} \cdot \left\lceil \frac{\Delta R}{\delta R} \right\rceil \cdot \left(\left\lceil \frac{\Delta u}{\delta U} \right\rceil \left\lceil \frac{\Delta v}{\delta V} \right\rceil \right) \right\} \tag{10}$$

Where: $n_{SearchDwells}$ = total number of required dwells to cover search volume

δR = Receive Window Width (Meters)

e_{volume} = Search Efficiency

ΔR = Search Range Extent (Meters)

The total time to search the entire search volume is the product of the time per dwell and the number of dwells. However, the model does not yet account for probability of detection or probability of false alarm.

2.6 Probability of Search Detection

The probability of detection (P_d) is the probability that the radar will correctly conclude a target is present in a dwell. Failure to detect the presence of a target will result in additional dwells being necessary to find the target in a search pattern. For this Value Model, the search pattern does not overlap in angles or range. Therefore, if the target is not detected in the dwell in which it is present, it will result in the entire search pattern to be repeated. Therefore, the number of scans required until the target is detected follows a Geometric Distribution (Montgomery, Runger and Hubele, 2010), with a mean equal to the inverse of the P_d. Therefore, the expected search time to detect the target is the expected number of scans multiplied by the time per scan, shown in Equation (11).

$$E[n_{SearchScans}] = \frac{1}{P_d} \tag{11}$$

Where: $n_{SearchScans}$ = the average number of scans required to detect target

2.7 Total Acquisition Time

The total acquisition time is therefore shown in Equation (12).

$$t_{acquisition} = E[n_{SearchScans}] \times n_{SerchDwells} \times t_{Measure} \tag{12}$$

Plugging in Equations (8), (10) and (11) into Equation (12) yields Equation (13).

$$t_{acquisition} = \frac{\left\{e_{volume} \cdot \left\lceil\frac{\Delta R}{\delta R}\right\rceil \cdot \left(\left\lceil\frac{\Delta u}{\delta U}\right\rceil \left\lceil\frac{\Delta v}{\delta V}\right\rceil\right)\right\}\left\{\left\lceil\frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi}\right\rceil \cdot PRI + t_{Process}\right\}}{P_d} \tag{13}$$

2.8 Radar Confirmation Function

After the radar determines that a target is present, it schedules a confirmation dwell to determine with high probability that the detection was indeed a target and not a false alarm. This is because the probability of a false detection in Search and Confirmation is the product of the two false alarm probabilities.

If successful, confirmation time is the time required to perform a single dwell, given in Equation (8). However, there are two conditions concerning the confirmation dwell that can impact the Value Model. The first is the results of the confirmation dwell concluding that no target was present, when the target correctly detected in the Radar Search Function. The second is the additional confirmation dwells required due to search false alarms.

2.9 Failed Confirmations

Failed Confirmations impact the value model similarly to failed search detections. In fact, failed Confirmations have the exact same effect on the acquisition time because a failed Confirmation results in reverting back to search mode and resuming the acquisition scan. The overall probability of detection is therefore the combined probability of detection in Search and probability of detection in Track. This is shown in Equation (14).

$$P_d = P(confirmation|search\ detection) = P_{searchDetection}P_{confirmationDetection} \tag{14}$$

Where: $P_{searchDetection}$ = Probability of Search Detection

$P_{confirmationDetection}$= Probability of Conformation Detection

Plugging Equation (14) into Equation (13) yields Equation (15).

$$\boxed{t_{acquisition} = \frac{\left\{e_{volume} \cdot \left\lceil\frac{\Delta R}{\delta R}\right\rceil \cdot \left(\left\lceil\frac{\Delta u}{\delta U}\right\rceil \left\lceil\frac{\Delta v}{\delta V}\right\rceil\right)\right\}\left\{\left\lceil\frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi}\right\rceil \cdot PRI + t_{Process}\right\}}{P_{searchDetection}P_{confirmationDetection}}} \tag{15}$$

2.10 Search False Alarms

False alarms during the acquisition scan lead to additional time in the value model due to the subsequent confirmation dwell perfumed to determine the detection was actually a false alarm. The radar will initiate a confirmation dwell in response to a false search detection. For this model, it is assumed the probability of false alarm for the confirmation dwell is zero. The false alarm probability of the confirmation pulse is often very low (less than 10^{-6}) meaning that this assumption has little effect on the value model.

The expected number of confirmation pulses required is the number of confirmation pulse due to false search detections plus the single confirmation pulse corresponding to the correct target detection. This is shown in Equation (16).

$$E[n_{confirmationDwells}] = 1 + P_{searchFA} E[n_{SearchScans}] n_{SerchDwells} \tag{16}$$

Where: $E[n_{confirmationDwells}]$ = expected number of confirmation dwells

$P_{searchFA}$ = Probability of false alarm in search

2.11 Total Confirmation Time

The total time required for the Confirmation mode in the expected number of confirmation dwells computed in Equation (16) multiplied by the time required for each dwell, shown in Equation (8). The result is shown in Equation (17).

$$\boxed{\begin{aligned} t_{verification} &= E[n_{confirmationDwells}] \cdot t_{Measure} \\ &= (1 + P_{searchFA} E[n_{SearchScans}] n_{SerchDwells}) \left\{ \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI \right. \\ &\quad \left. + t_{Process} \right\} \end{aligned}} \tag{17}$$

2.12 Radar Track Function

After the radar has detected and verified the target, it will initiate a sequence of track pulses in order to collect sufficient data to generate the required number of Obs. Therefore, the basic form of the track time is shown in Equation (18).

$$t_{track} = n_{obs} \cdot n_{dwellsPerOb} \cdot t_{measure} \tag{18}$$

Where: n_{obs}= number of Obs requested by JSpOC

$n_{dwellsPerOb}$ = The number of radar dwells required to generate an Ob

The Obs are required to be of sufficient accuracy for the required orbital updates at JSpOC. Therefore, the number of radar dwells required to generate an Observation is a function of the measurement precision (sigma) for each dwell and the required precision of the Observation. The precision of a single radar measurement (Curry, 2005) is related to the SNR of the return as shown in Equation (19).

$$\sigma_{Dwell}^2 = \sigma_X^2 + \sigma_Y^2 + \sigma_Z^2 \propto \frac{1}{SNR} \tag{19}$$

Where: σ_{Dwell}^2 = The total variance of the radar measurement

σ_X^2 = The variance of the radar measurement in the x dimension

σ_Y^2 = The variance of the radar measurement in the y dimension

σ_Z^2 = The variance of the radar measurement in the z dimension

Solving for the SNR yields Equation (20) (Curry, 2005).

$$SNR \propto \frac{1}{\sigma_{Dwell}^2} \tag{20}$$

As the radar collects multiple measurements of the target, the precision of the smoothed measurement improves. Assuming Gaussian distributed errors, the Ob variance is related to the dwell variance by Equation (21) (Montgomery, Runger and Hubele, 2010).

$$\sigma_{Ob}^2 = \frac{\sigma_{Dwell}^2}{n_{dwellsPerOb}} \tag{21}$$

Where: σ_{Ob}^2 = The total variance of the radar Ob required by JSpOC

Therefore, the number of dwells required per Observation is shown in Equation (22).

$$n_{dwellsPerOb} = \left\lceil \frac{\sigma_{Dwell}^2}{\sigma_{Ob}^2} \right\rceil \tag{22}$$

Therefore, plugging Equation (8) and Equation (22) into Equation (18), we can create an equation for the track time required. This is shown in Equation (23).

$$\boxed{t_{track} = n_{obs} \left\lceil \frac{\sigma_{Dwell}^2}{\sigma_{Ob}^2} \right\rceil \cdot \left\{ \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI + t_{Process} \right\}} \tag{23}$$

2.13 The Value Model

The final value model can be computed by substituting Equations (15), (17) and (23) into Equation (2). This is shown in Equation (24).

$$\boxed{\begin{aligned} t_{collection} = {} & \frac{\left\{ e_{volume} \cdot \left\lceil \frac{\Delta R}{\delta R} \right\rceil \cdot \left(\left\lceil \frac{\Delta u}{\delta U} \right\rceil \left\lceil \frac{\Delta v}{\delta V} \right\rceil \right) \right\} \left\{ \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI + t_{Process} \right\}}{P_{searchDetection} P_{confirmationDetection}} \\ & + (1 + P_{searchFA} E[n_{SearchScans}] n_{SerchDwells}) \left\{ \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI \right. \\ & \left. + t_{Process} \right\} + n_{obs} \left\lceil \frac{\sigma_{Dwell}^2}{\sigma_{Ob}^2} \right\rceil \cdot \left\{ \left\lceil \frac{SNR \cdot L_{Scan} \cdot R^4}{\sigma \cdot \psi} \right\rceil \cdot PRI + t_{Process} \right\} \end{aligned}} \tag{24}$$

3 SYSTEM ANALYSIS EXAMPLES

3.1 Trade Study

A trade study is conducted on two designs to evaluate which design will allow the radar to produce more Obs per day. The trade study uses the value model developed in this paper to decide which design is best.

Consider a notional radar system design that has the nominal parameters shown in Table 1:

Table 1. Datum Design Parameters

Radar Parameters	Value	Units
Range Window Width	1000	meters
Range Search Extent	5000	meters
u Beamwidth	0.02	sines
u Search Extent	0.05	sines
v Beamwidth	0.02	sines
v Search Extent	0.03	sines
Detection SNR	18	dB
Loopgain	280	dB
PRI	0.025	seconds
Process Time	1	seconds
Pd(Search)	0.9	
Pd(Verify)	0.95	
Pfa(Search)	0.00001	
Dwell Standard Deviation	490	meters
Scan Loss	1	dB
Search Efficiency	1	
Target Parameters		
Range	20,000	km
Cross Section	5	sq-meters
JSpOC Parameters		
Ob Standard Deviation	200	meters
Number of Obs	3	

Two alternative designs are proposed. The first alternative utilizes a different waveform that offers better radar Loop Gain of 285dB at a cost of reduced dwell deviation of 632 meters. The second alternative offers faster processing time for each dwell of 0.5 seconds at a cost of reduced range extent of 700 meters.

Traditional requirements-based engineering approaches are inadequate at evaluating these alternatives. Using the derived Value Model, this is a straightforward exercise. The total time required is computed using Equation (24) for each alternative is shown below in Table 2.

Table 2. Evaluation of Design Alternatives

Design	Collection Time (sec)
Datum	**303.04**
Alternative 1	**159.54**
Alternative 2	**346.52**

Design alternative 1 is the preferred design for this trade study. However, had both the alternatives met the requirements in the specification, there would have been no rigorous way to evaluate the alternatives using traditional requirements-based engineering. In addition to performance analysis trades, the utility metric can be combined with expected Utility Theory to account for uncertainty in the design alternatives. This has been shown by Collopy (2002).

3.2 System Optimization

Value Models can be minimized or maximized to find the optimal parameters for a system. In this example, the collection time is minimized to find the optimal SNR and range window width. The number of pulses per dwell, probability of false alarm in search, process time and probability of detection in search are dependent of the two variables being optimized. The rest of the variables are the same as in Table 1 from the trade study above. Both the independent variables being optimized and dependent variables are constrained in this example.

The system constraints are:

$$14dB < SNR$$

$$100\ meters < \delta R < 1000\ meters$$

$$n < 2400$$

$$P_{searchFA} < 0.001$$

$$0.8 < P_{searchDetection}$$

The optimization method chosen must handle a non-differentiable Objective Function, constraints on independent and dependent variables, and find the global minimum. Some of the equations used to calculate the variables dependent on the variables being optimized cause the Objective Function to be non-differentiable. Also, both the independent and dependent variables being optimized are constrained. The basic concept of the optimization algorithm used in this section is based around iteratively changing the boundaries to enclose the interval of uncertainty, similar to the procedure discussed by Rao (2002) using the Fibonacci Method for optimization in his book called Applied Numerical methods for Engineers and Scientist (2002). Below are the steps of the optimization algorithm used in this example.

1. Define the boundaries of independent variables being optimized using the constraints.
2. Make an array larger than three values for each independent variable from step 1 as shown below: [lower boundary, multiple values in between boundaries, upper boundary]
3. Perform a multi-dimensional, exhaustive search using the arrays in step 2 where the independent variables used for the minimum is saved as the optimal independent variables.
   a. Where, Objective Function = collection time + penalty function
      i. Penalty function is used for constraints on variables dependent on independent variables.
4. For all independent variables, remake the upper and lower boundaries depending on the SNR and range window width for the minimum collection time.
   a. If the optimal independent variable is equal to the lower boundary, then change the upper boundary to the third value in the array. Keep the lower boundary the same.
   b. If the optimal independent variable is equal to the upper boundary, then change the lower boundary to the third from the last value in the array. Keep the upper boundary the same.
   c. Otherwise, change the lower boundary to the value in the array that is one index to the left of the optimal value. Change the upper boundary to the value in the array one index to the right of the optimal value.
5. Repeat steps 2 thru 4 until the arrays in step 2 converge.
6. Compare the final answer to the penalty function to confirm the final answer met the constraints.

A demonstration of the process above with a simple objective function and no penalty function is shown in Figure 3 using a contour plot. The demonstration used 5 values per array in step 2 above. The optimal values each iteration is boxed in the figure.

Where: $Objective\ Function = |x - 4| + |y + 2|$

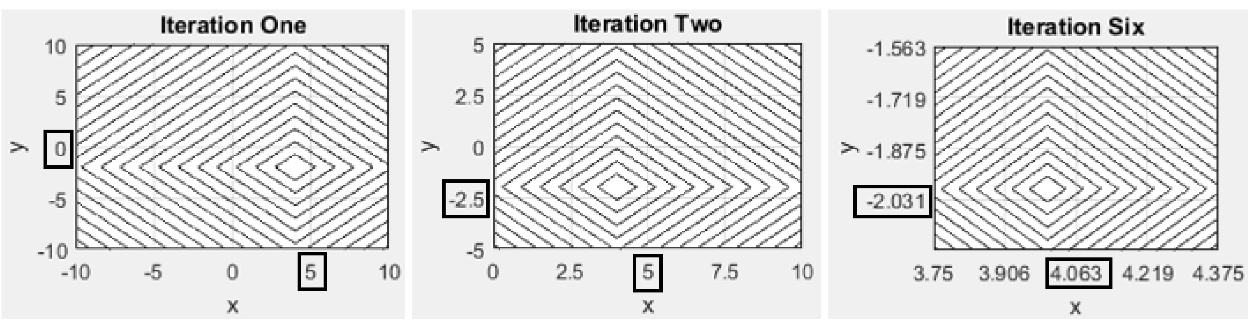

Figure 5. Demonstration of Re-Bounding Each Iteration

For an exhaustive search if the minimum is at the value x_3 the final interval of uncertainty lies between the two values x_2 and x_4 assuming the function is unimodal (Rao, 2002). Thus, the algorithm above is a multi-dimensional, exhaustive search that changes the upper and lower boundaries of each iteration to enclose the new interval of uncertainty. The algorithm is iterated until converged on a desired interval of uncertainty. If the function is not unimodal, then using more values in step 2 above increases the chances of converging on the global minimum. If the Fibonacci Method demonstrated by Rao (2002) for one independent variable is applied here, only four values can be used per array in step 2 and the two middle values in the array become exponentially closer each iteration. Thus the algorithm in the steps above is slower at converging but is more likely to converge on the global minimum.

Applying the algorithm in the steps above using the Value Model as the Objective Function and specified system constrains, the optimal values are:

$t_{collection}$ = 164.61 seconds

SNR = 14.013 dB

δR = 830 meters

n = 102

$P_{searchFA}$ = 0.00096254

$P_{searchDetection}$ = 0.89974

4 CONCLUSION

Value Models are an effective means for evaluating performance tradeoffs in the presence of uncertainty. In this paper, a Value Model defining the total amount of time a Space Surveillance Network radar takes to collect a given number of Observations on a target in Deep Space has been derived. This Value Model allows for quick comparison of designs for existing and future SSN radars and optimization of radar parameters. The Value Model was demonstrated in a trade study and system optimization. A method for system optimization using the proposed Value Model was developed for the unique circumstances of the Value Model.

REFERENCES

[1] P. Collopy, "Economic-Based Distributed Optimal Design", AIAA Space 2001 Conference and Exposition (2001): 1-9.

[2] P. Collopy and R. Horton, "Value Modeling for Technology Evaluation", American Institute of Aeronautics and Astronautics (2002).

[3] P. Collopy, "Adverse Impacts of Extensive Attribute Requirements on the Design of Complex Systems", 7th AIAA

[4] Aviation Technology, Integration and Operations Conference (Sept 2007): 1-7.

[5] G. Richard Curry, *Radar System Performance Modeling* (Norwood, MA: Artech House, 2005).

[6] Douglas M. Montgomery, George C. Runger and Norma Faris Hubele, *Engineering Statistics* (Danvers, MA: John Wiley and Sons, 2010).

[7] 2d. Lt. Linea Stuckey, "20th Space Control Squadron: AFSPC's Premier Space Surveillance Squadron", Space Daily, Dec 14, 2011, http://www.spacedaily.com/reports/20th_Space_Control_Squadron_AFSPC_premier_space surveillance_squadron_999.html

[8] Rao, S. S. (2002). Applied Numerical Methods for Engineers and Scientist. Upper Siddle River (NJ): Prentice Hall

Unmanned Aerial Systems Transfer of Training

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Abstract: The purpose of the research was to identify how to best train individuals to successfully and safely operate UASs. This research determined if the use of simulation training while learning to operate UAS was beneficially transferred to operating real UAS quadcopters. A secondary goal was to identify if performance in operating a UAS was better from participants with flight experience. There were 31 participants recruited for this study. The research findings are discussed regarding the performance between the Simulator and Non-Simulator Training groups and performance between those with flight experience. Additional findings on training and gender, training and video game experience, training and native versus non-native, and training and English proficiency are also addressed. Conclusions to include future research are discussed.

1 INTRODUCTION

The purpose of this research was to identify how to best train individuals to successfully and safely operate UASs. The specific goal of the study was to identify the optimal method for training UAS operators through testing different methods for effectiveness in training UAS operators. This research determined if the use of simulation training while learning to operate UAS was beneficially transferred to operating real UAS quadcoptors. This was achieved by placing participants in one of two groups. Group A was trained on selected tasks using UAS simulation software. Once the participants successfully completed the tasks within the simulation, the participants were tested on the same tasks using a UAS to determine if transfer of training occurred from the simulated to real-world environment. Group B participants were tested only in a real-world environment. In other words, no simulation training occurred in Group B. The primary research question for this study was to assess whether there would be performance benefits from having the simulation training versus no simulation training. A secondary goal was to identify if performance in operating a UAS was better from participants with flight experience.

2 LITERATURE REVIEW

With the growing use of UASs, there is a need to properly train operators (Demir, Cicibas, & Arica, 2015). The FAA's mission is for the nation's airspace and aircraft to be safe bringing about the need to regulate certification and training for small UASs (FAA, 2017a; FAA, 2017b). The FAA developed the Remote Pilot Airman Certification Standards requiring Commercial Small UAS pilots to obtain a FAA issued Remote Pilot Certificate (RPC) (FAA, 2017b). While equipment failure has caused some of the accidents, human error is a significant casual factor in UAV mishaps and accidents (Rash, Leduc, & Manning, 2006; Williams, 2006). Human Factors issues and lack of operator training are among the top reasons for poor performances with UASs operations (Damilano, Guglieri, Quagliotti, & Sale, 2012).

Hing and Oh (2009) have studied human factors and specifically factors to improve pilot operator control when operating UASs with a focus to decrease potential accidents. Their research examined the use of simulation as a training tool so that transfer of training skills to the real-world operation of UASs would occur. A tele-operation paradigm that employs motion cueing was developed by the researchers as a flight training tool that improves UAS operator performance.

Spatial disorientation is another area of interest with regards to simulation training. Research was conducted to train UAS operators to experience and learn to control for spatial disorientation (Self, Ercoline, Olson, & Tvaryanas, 2006). This learning can be transferred from a simulated environment into the real-world with the benefit of not having the financial and safety risks in the real-world due to risks to humans and UASs. Rigby, Macchiarella, & Mirot (2017) and Macchiarella and Mirot (2018) have also studied the concept of training transfer whereby simulators are used as training practices for UASs. Their research involved participants learning a task using a computer-based simulator and then having the same task performed in the real-world also demonstrating simulation as a useful training tool.

3 METHODS

The purpose of the proposed research was to identify how to best train individuals to successfully and safely operate UASs. The specific goal of the study was to identify the optimal method for training UAS operators through testing different methods for effectiveness in training UAS operators. A highly maneuverable four-bladed quadcopter was the type of UAS utilized for the study. The target population was any person across the country. The accessible population for this study were participants consisting of students, staff and faculty on a university campus. The sample that was used in this study was not selected based upon gender, age, and experience and instead were selected among those in the accessible population that were willing and available to participate. Participants were recruited via email to a university campus community. Statistical tests were performed and are discussed in detail in the results section of this manuscript.

Institutional Review Board (IRB) approval was obtained prior to conducting any trials with human subjects. Participants were informed that no identifiable information would be collected during the study. Due to participants interacting with a UAS, specifically an UDI R/C U817A quadcoptor regardless of which group assignment, participants received safety briefings and safety glasses prior to operating the UAS. Participants in both groups begin by watching a UAS training video on “Heli Controls” to learn how to operate the controls. The total time of the video was 6.17 minutes.

Participants were then randomly assigned one of two groups. Group A completed a UAS training protocol utilizing the desktop computer software, Real Flight 7.5 UAS Simulator. The training was comprised of the following:

1. Flight training to practice basic control of the X8 Quad 1260. This training allowed participants to become familiar with the controls and to experience how the simulated quadcopter responded to inputs. Maneuvers included taking off, landing and hovering. The total training time was 14 minutes 10 of which was actual flying time within the simulator. The time not flying involved setup and instruction.
2. Flying challenge training with the X8 Quad 1260. In this training segment, participants advanced to different levels after mastering skills in takeoff, landing and navigating an obstacle course. The total training time was 30 minutes, 15 of which was flying time. The time not flying involved setup, instruction, and break time.
3. Flight maneuver practice with the X8 Quad 1260. In this training segment, participants continued to practice the skills learned during the training. The total training time was 7 minutes, 5 of which was flying time. The time not flying involved setup time.
4. Basic flight training flying the Quadcopter X. This training segment focused on maintaining UAS control while taking off, landing, rolling, yawing, pitching, and also maintaining orientation awareness. The total time was 12 minutes 10 of which was flying time. The time not flying involved setup time.
5. Flying challenge training with the Quadcopter X. In this training segment, participants advanced to different levels after mastering skills in takeoff, landing and navigating an obstacle course. The total time was 27 minutes, 15 of which was flying time. The time not flying involved the setup, instruction, and break time.

Group B participants completed a UAS training protocol utilizing minimal training with the UAS, UDI R/C U817A quadcoptor. This was comprised of the following:

1. Orientation and safety training where participants were given basic instruction in operating the U817A quadcopter. Instruction was given in how throttle and stick inputs control the aircraft, how to properly hold the remote control, how to recognize a low battery situation, and the proper actions to take when this occurs. Participants were reminded of all safety protocols, with an emphasis on maintaining safe distances from people, actions during a loss of control, or after a crash. The total time was 5 minutes.

After the training protocol, participants from both groups completed a flight evaluation using the UDI R/C U817A quadcopter. However, Group A was first provided with the same orientation and safety training mentioned in step 1 above in the Group B training protocol. Whereas, Group B was re-briefed on the safety procedures. For the flight evaluation, participants in both Groups A and B, operated the UDI R/C U817A quadcopter through an obstacle course. The obstacle course is displayed in Figure 1. The participants' quadcopter activities through the obstacle course were filmed during the evaluation.

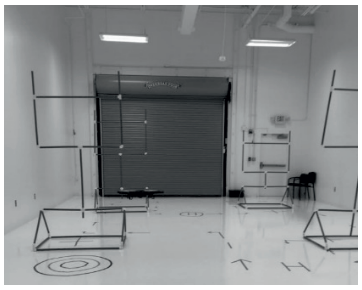

Figure 1. Obstacle Course

The flight evaluation started with 5 minutes of instruction on how participants were to complete the evaluation obstacle course, as well as the criteria that was used to assess the performance level. The criteria used are listed below:

1. Time to completion cannot exceed 240 seconds. Completion required all obstacles to be successfully navigated in order.
2. If obstacles were completed out of order, they counted towards "absolute obstacles." Obstacles completed in order were included in the "absolute" column and the "in order" column.
3. Number of obstacles successfully completed in order could not exceed three.
4. Bumps were defined as the quadcopter coming into contact with an obstacle (including the ground) but not crashing. If a participant chose to make a controlled landing, and then takeoff again (without resetting), the timer continued (was not paused) and counted as a "bump."
5. Sometimes the quadcopter had a bump several times in the process of crashing. As a rule of thumb, if repeated bumps were associated with a crash (within about 3 seconds), it counted only as a crash.
6. Any crash, directed reset, or optional reset required the participant to restart from the beginning (timing was paused).
7. If a proctor saw any situation developing that would damage the quadcopter and/ or become a threat to safety, it resulted in a "directed reset."
8. The timer was paused for crashes, proctor directed resets, or optional resets.
9. If any problems arose with the quadcopter (low battery for example), the proctor paused the timer, fixed the problem, and re-started the participant from where they had the problem.

4 RESULTS

A total of 31 subjects participated in the study. There were 18 participants in the Non-Simulation Training group (58%), and 13 in the Simulation Training Group (42%). The mean age and standard deviation (SD) for the 31 participants was 28.5/11.5 years. Out of a total of 31 participants, 19 had no previous flight experience (61.3%), whereas 12 had some flight time (38.7%). Considering just those that had flight experience, the mean flight time was 1984 hours, with a SD of 1914 hours. The rather large SD is accounted for by the wide range of flight time; the range of flight time was from 5 to 6,000 hours. A number of additional demographic variables were analyzed for this study; the following are the primary demographic characteristics and do not include all such variables that were included in the study (see Table 1). Table 2 presents a subset of the performance variables that were included in the study, and do not represent all such performance variables that were gathered.

Table 1. Frequency of Selected Demographic Variables

UAS Experience		
	Frequency	Percent
None	23	74.2
Some	8	25.8
Total	31	100.0
Academic Level		
	Frequency	Percent
Freshman	3	9.7
Sophomore	2	6.5
Junior	1	3.2
Senior	5	16.1
Grad Student	18	58.1
Other	2	6.5
Total	31	100.0
Video Game Experience		
	Frequency	Percent
None	2	6.5
Little	10	32.3
Some	10	32.3
Significant	9	29.0
Total	31	100.0

English Background		
	Frequency	Percent
Native	17	54.8
Non-native	14	45.2
Total	31	100.0
Ethnic Background		
	Frequency	Percent
Caucasian	10	32.3
African American	4	12.9
American Indian	2	6.5
Hispanic	4	12.9
Asian	9	29.0
Other	2	6.5
Total	31	100.0
Gender		
	Frequency	Percent
Male	27	87.1
Female	4	12.9
Total	31	100.0

Table 2. Descriptive Statistics for Selected Performance Variables

	N	Minimum	Maximum	Mean	Std. Deviation
Time to Complete Course	31	21.0	240.0	190.5	72.7
Bumps	31	0	44.0	17.5	12.9
Crashes	31	0	8.0	1.2	1.9
Completed Obstacles	31	0	8.0	3.0	1.9
Total Composite Score	31	2.7	10.0	7.1	2.0

4.1 Selected Quantitative Statistical Analysis

A scoring algorithm was developed. Two graduate students were employed to observe participant performance and scored several of the performance variables. Inter-rater reliability between the two was high; the correlation between the two raters on Bumps was .957 ($p < .001$), .932 ($p < .01$) for Completed Obstacles, and .949 ($p < .001$) for Crashes. The Total Composite Score was a derivative (average) of six individual performance outcomes (Time, Completed Obstacles, Bumps, Crashes, Proctor Directed Resets, and Optional Resets). The Total Composite Score ranged from 1 to 10, with 10 indicating the best possible score, 1 indicating the worst. For each metric except Completed Obstacles, a low score signified better than a high score. For each of the six metrics, the range of possible scores from highest score and lowest score were examined and matched to the 1 to 10 scale. For Time, the scores ranged from 21 to 240. It is uncertain what the absolute best time to complete the obstacle course could be, but 21 seconds was selected as very close to a "best possible time." Therefore, this range of scores was matched to the 1-10 scale by dividing time scores into 10 equally spaced segments. A score of 20-42 seconds would yield a 10, 43-64 seconds would yield a 9, etc. For Bumps, the scores ranged from 0 to 44. The upper end of this range does not represent the absolute worst that someone could do. In this case, 0-4 bumps yielded a score of 10, 4.5-8.8 bumps yield a 9, etc. Crashes, Completed Obstacles, Proctor Directed Resets, and Optional Resets were calculated in the same manner as Bumps. The above methodology provided individual scores from 1 to 10 (10 being the best), for each of these six metrics. From here, a simple average of the individual scores for each metric was taken to have a resultant Total Composite Score ranging from 1 to 10. This methodology would not weigh any particular metric more than another.

There are a multitude of algorithms that could have been used, but this one was deemed reasonable and equally weighted each performance measure.

4.2 Analysis

The primary research question for this study was to assess whether there would be performance benefits from having the simulation training versus no simulation training. There was also interest in examining whether there would be differences in performance between those who had flight experience compared to those who were not participating in the flight program. As mentioned earlier and to simplify analyses, a composite performance score was used for the dependent variable. Given the number of variables involved in this study, there could have been a large number of analyses. The researchers focused on what was believed to be the most important variables for the analyses.

The first analysis examined if there was a significant difference in performance between the Simulator Trained versus Non-Simulator Trained groups. Given the algorithm used to calculate the composite score, values could range from 1 to 10 (this is the case with all the following analyses). The mean/SD of the Non-Simulator group was 7.0/2.0, while the mean/SD of the Simulator group was 7.2/1.9. The independent t test determined this difference was not significant, $t(29) = -.267$, $p > .05$. The other primary analysis that was conducted was to examine whether there would be a difference in performance between those who had flight experience versus those who did not have any flight experience. The mean of the group with no flight experience was 6.7, SD was 2.0. The mean performance for the group that had flight experience was 7.8, with a SD of 1.8. While the group that had flight experience did perform better, the resulting t test conducted was insignificant, $t(29) = -1.6$, $p > .05$. Given this difference was insignificant, researchers examined selected combinations of variables. As a result, numerous factorial ANOVA analyses were conducted. The first ANOVA conducted was a 2 x 2 (Training Type—Simulator versus Non-Simulator and UAS Experience—None versus Some) factorial. Again, the performance composite score was used. The main effect for Training was not significant, $F(1,27) = <1$, $p > .05$; nor was the interaction of Training Type and UAS Experience, $F(1,27) = <1$, $p > .05$. However, the main effect for UAS Experience was significant, $F(1,27) = 8.2$, $p < .01$. The mean/SD for the None group (no experience) was 6.5/1.8, while the mean/SD for the Some experience group was 8.7/1.5.

Next, the researchers examined the combination of Training and Gender 2 x 2 factorial design. None of the main effects, nor the interaction was significant. While the main effect of Gender was not significant ($p = .10$) it did show that males performed better than females (Male M/SD = 7.3/1.9; Female M/SD = 5.3/.7) based on the composite performance score. Next, Training versus Video Game Experience (None, Little, Some, and Significant experience) was examined. Thus, a 2 x 4 factorial ANOVA was conducted. The main effect for Training and the interaction between Training and Video Game Experience was not significant. However, the main effect of Video Game Experience was nearly significant, $F(1,3) = 2.8$, $p = .06$. The means/SDs for None, Little, Some and Significant experience were: 5.1/3.4, 6.2/1.9, 7.6/1.5, and 7.9/1.8, respectively. Next, the combination of Training and English (Native vs Non-native) resulted in the 2 x 2 factorial ANOVA. None of the effects, main or interaction, were significant. The final ANOVA combination included the factors Training and English Proficiency (Neutral, Somewhat, and Completely). The 2 x 3 factorial ANOVA was not significant on either main effects or interaction.

The final quantitative analysis examined specific correlations between a subset of the variables. The following variables were submitted to a Pearson correlational analysis: UAS Experience, Academic Level, Video Game Experience, English Proficiency, Time to Complete, GPA, and Total Composite Performance Score. The correlations that were significant included: UAS Experience and Total Composite Performance Score ($r = .487$, $p < .01$); UAS Experience and Time ($r = -.465$, $p < 01$); UAS Experience and Bumps ($r = -.382$, $p < .05$); Video Game Experience and Total Composite Performance Score ($r = .443$, $p < .05$); Video Game Experience and Bumps ($r = -.365$, $p < .05$); Total Composite Performance Score and Time ($r = -.824$, $p < .01$); Total Composite Score and Bumps ($r = -.906$, $p < .01$); Time and Bumps ($r = .722$, $p < .01$).

5 DISCUSSION

While the difference in performance between the Simulator and Non-Simulator Training groups was insignificant, it indicated that the group that received the simulation training did better. It was also found that the group that had flight experience did perform better than the group that did not have any experience; but again, this difference was statistically insignificant. The reason these differences were not significant could be due to several limitations of the present study. First, with a rather small sample (18 in the non-simulator and 13 in the simulator group; 19 in the no flight experience group and 12 in the flight experience group), the differences may not have been evident due to reduced power to detect any differences if they existed. The simulator group also had fewer subjects which may have contributed to the non-significant effect. The other limitation of the present study was the metric used to evaluate performance. It was a composite score based on what was believed to be a reasonable algorithm. It's possible other measures of performance may have uncovered additional differences between the two groups. However, taking into consideration the correlational data, it would appear that the algorithm was apparently a good performance metric as it correlated positively with UAS Experience, Video Game Experience, and negatively with Time and Bumps.

The difference in performance between males and females, while not quite significant, was interesting. It would be important to examine prior literature in this area to determine if UAS performance has been examined for gender differences. The other analyses that examined the combination of variables (ANOVAs), did not demonstrate any major differences. However, the practitioner message is that while simulation training may or may not impact UAS performance, experience whether that of UAS or video games, does appear to positively influence UAS performance compared to that of individuals with less experience.

6 CONCLUSION

The purpose of the proposed research was to identify how to best train individuals to successfully and safely operate UASs. The research findings were discussed with the most interesting discussion point being that although performance between the Simulator and Non-Simulator Training groups was insignificant, UAS or video game experience positively influenced UAS performance. With regards to future research efforts, repeating the study but increasing the sample size and having equal participants in both groups, and adjusting the metric used to evaluate performance could yield different findings. Furthermore, studying simulated training and the impact on potentially reducing training costs, safety incidents and replacement costs from damaged UASs would be another area of future research. Studies on increased realism in simulator tools and the impact that has on transfer of training should also be further investigated (Macchiarella & Mirot, 2018). A study focused on stressors exposed to during training that are more in alignment to stressors in the real-world and the impact this has on transfer of training to the real-world environment should also be further explored (Cohen, Brinkman, & Neerincx, 2015). Lastly, a large-scale study should be explored to research the differences in performance between males and females, video game experience, and flight experience should be further studied.

REFERENCES

[18] Damilano, L., Guglieri, G., Quagliotti, F., & Sale, I. (2012). FMS for unmanned aerial systems: HMI issues and new interface solutions. Journal of Intelligent & Robotic Systems, 65(1-4), 27-42. doi:http://dx.doi.org.portal.lib.fit.edu/10.1007/s10846-011-9567-3

[19] Demir, K.A., Cicibas, H., & Arica, N. (2015). Unmanned aerial vehicle domain: Areas of research. Defense Science Journal. 65(4), 319-329.

[20] Cohen, I., Brinkman, W. P., & Neerincx, M. A. (2015). Modelling environmental and cognitive factors to predict performance in a stressful training scenario on a naval ship simulator.

[21] Cognition, Technology & Work, 17(4), 503-519. https://doi.org/10.1007/s10111-015-0325-3.

[22] Federal Aviation Administration (FAA). (2017a). Mission. https://www.faa.gov/about/mission/

[23] Federal Aviation Administration (FAA). (2017b). Airman Testing. https://www.faa.gov/training_testing/testing/

[24] Hing, J. T., & Oh, P. Y. (2009). Development of an unmanned aerial vehicle piloting system with integrated motion cueing for training and pilot evaluation. Journal of Intelligent & Robotic Systems, 54(1-3), 3-19. doi:http://dx.doi.org.portal.lib.fit.edu/10.1007/s10846-008-9252-3

[25] Macchiarella, N. D., & Mirot, A. J. (2018). Scenario development for unmanned aircraft system simulation-based immersive experiential learning. Journal of Aviation/Aerospace Education & Research, 28(1), 63-79. doi:http://dx.doi.org.portal.lib.fit.edu/10.15394/jaaer.2018.1773

[26] Rash, C.E., Leduc, P.A., Manning, S.D. (2006). Human factors in U.S. military unmanned aerial vehicle accidents. Advanced Human Performance Cognition Engineering Research, 7, 117–131.

[27] Rigby, K. T., Macchiarella, N. D., & Mirot, A. (2017). Enhanced Scenario-Based Training for Unmanned Aircraft System Operational Missions. Proceedings of the AIAA Modeling and Simulation Technologies Conference, AIAA SciTech Forum, (AIAA 2017-1309), Grapevine, TX. https://doi.org/10.2514/6.2017-1309

[28] Self, B.P., Ercoline, W.R.,Olson, W.A., Tvaryanas, A.(2006). Spatial disorientation in uninhabited aerial vehicles. In: Cook, N. (ed.) Human Factors of Remotely Operated Vehicles, 7, 133–146.