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These proceedings would not have been made possible without the valuable contributions of our Track Chairs and reviewers for the time and effort they spent reviewing the papers and coordinating our conference sessions. Thank-you also to our Administrative Coordinator, Elki Issa, whose work behind the scenes helps make our Conference a success.

We look forward to seeing you at IEMS 2019!

Warmest Regards,

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Flight Students' Willingness to Fly Within or Over Airspace Containing Operating Unmanned Aerial Systems

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Abstract

The increased usage of unmanned aerial systems (UASs) has necessitated new regulations to safely integrate them into the national airspace system (NAS). Consequently, pilot perception of UAS operation within the airspace is an area of increasing academic and industry relevance as increasing numbers of operating UASs translates to a greater likelihood of an encounter between a manned aircraft and a UAS. This study examined collegiate flight students' self-reported willingness to fly within or above airspace that is shared with an operating UAS. A survey using the Willingness to Fly scale developed by Rice et al. (2015) presented three flight scenarios to flight students of the Florida Institute of Technology. Flight student willingness to fly differed significantly based on the presence of an active, operational UAS.

1. Introduction

The popularization of unmanned aerial systems (UASs) has warranted the introduction of a plethora of new strategies, technologies and policies so as to ensure their safe integration into the national airspace system (NAS). While significant progress has been made in the education and regulation of UAS operators, one cannot ignore the importance of the perceptions of manned aircraft pilots as a component of sound UAS integration. A better understanding of how manned aircraft operators perceive UAS operations in the NAS is critical to the coexistence of manned and unmanned aircraft in the same airspace.

2. Problem statement

The purpose of this study was to determine collegiate flight students' willingness to fly within or above airspace that is shared with an operating UAS. For the purpose of this study, shared airspace was defined as the co-occupancy of a cylindrical volume of five statute miles in radius that extends from the surface to 2,500 feet above ground level (AGL). Data was collected via a survey of the collegiate flight students of the Florida Institute of Technology and used the Willingness to Fly scale (Rice et al., 2015) to determine if willingness to fly varied with the presence of an active UAS, and whether the student is to fly through or over the airspace that the system occupies.

3. Significance and generalizability

Both the popularity and technological capabilities of UASs have increased dramatically, driving a need to actively regulate and integrate these platforms into the NAS. This study has provided data on collegiate flight students' willingness to fly within or above airspace with an operating UAS, and the results of this study may be used to evaluate if the presence of a UAS affects flight student decision-making in different flight scenarios while operating in close proximity to an unmanned vehicle. Consequently, the study may be used to illustrate the concerns of manned aircraft student pilots as a component in the development of a flight environment in which both manned and unmanned aircraft can coexist.

In the United States, there are two ways to conduct flight training: flight courses regulated under Title 14 of the Code of Federal Regulation Part 141 (14 CFR Part 141) or Title 14 of the Code of Federal Regulations Part 61 (14 CFR Part 61). Training under these parts varies slightly, but Part 141 training may be regarded as more consistent than Part 61 due to its more structured syllabus approval requirements by the Federal Aviation Administration (FAA). Most participants were Part 141 students and the distribution of respondents' flight courses closely matches that of the FIT pilot population; thus, the results can be immediately generalized to FIT student pilots, and may be application to Part 141 flight students given the standardized training requirements. Pilot perceptions are valuable to the formation and evaluation of strategies for the safe, secure, and efficient integration of UASs into the NAS.

4. Background

The integration of UASs into the NAS is a multifaceted problem that depends on the evaluation of contributing factors across disciplines. In order to understand pilot perceptions of operating in airspace with UAS, the following review discusses the safety of UASs, public perceptions of these systems, risk evaluation, and current UAS legislation and integration strategies.

A significant factor influencing the desire of manned aircraft pilots to share airspace with any form of new traffic is associated risk. First, the manner in which the system is perceived by pilots must be considered and then any significant risk to the safety of the flight. Slovic and Peters (2006) discussed how human beings generally assess risk. Risk perception may be broken down into two major categories: "risk as analysis" and "risk as feelings" (Slovic & Peters, 2006, p. 322). In their simplest forms, risk as assessment refers to the logical approach to risk assessment, while risk as feelings, or "the affect heuristic," refers to individuals' "instinctive and intuitive reactions to danger" (Slovic & Peters, 2006, p. 322). Fischhoff, Slovic, Lichtenstein, Read, and Combs (1978) showed a correlation between the perception of risk and the feeling of dread. Additionally, Slovic and Peters (2006) suggested an inverse relationship between perceived benefit and perceived risk, and asserted that the perception of risk may vary with the manner that data is presented. The severity of a consequence may cause individuals to neglect the probability of the occurrence of an event (Slovic & Peters, 2006). One may conclude that although risk evaluation and mitigation may be modelled based on logic, there exists a profound affective component that manipulates perceptions of risk, and, therefore, decisions made based on those perceptions.

Sjöberg (2000) illustrated the inherent difficulties in evaluating the perceptions of risk between individuals, or between individuals and a technical analysis. Of particular pertinence to an analysis of willingness to fly as a function of perceived risk is the concept of the individual "risk target" (Sjöberg, 2000, p. 2). Sjöberg (2000) found that, although each participant in a survey may be subject to similar risk levels, the perceptions of risk levels may vary as a function of the denial of risk among certain individuals. Furthermore, Sjöberg (2000) purported a correlation between risk perception and targeted fear. These assertions are consistent with the findings of Slovic and Peters (2006) discussed prior. It is also asserted that perceived risk may vary with personal attitude based on core values and beliefs, and personal sensitivities towards hazards and the manner in which those sensitivities influence an individual's interpretation and use of scales that attempt to measure the perception of risk (Sjöberg, 2000). It follows, therefore, that the empirical evaluation of risk perception is inherently skewed by individual interpretations of both the risk and the scale used to measure that risk.

Specifically with respect to UASs and perceived risk, Clothier, Greer, Greer, and Mehta (2015) sought to address contemporary risk perceptions of UASs by comparing public risk perceptions of UASs and manned aircraft, examining the impact of terminology on public risk perception, and determining general concerns that may influence acceptance of the technology. Clothier et al. (2015) asserted that, while the public perception of the safety of unmanned aircraft will be a major determinant in the proliferation of the technology, there had been, as of the date of completion of the study, no significant systematic

analysis of public perceptions of unmanned systems. Clothier et al. (2015) found a general correlation between terminology and risk perception. Furthermore, they concluded that risk perception may be affected by a number of factors including perceived benefit, knowledge of the subject area, control over exposure to risks, the degree to which exposure to risks is voluntary, the degree to which the hazard is new, the magnitude of the consequence (Clothier, et al., 2015), and the feeling of fear (Clothier, et al., 2015, Fischhoff, et al., 1978, Slovic & Peters, 2006). Having assessed the perceptions of a sample of the Australian public, the study reached the conclusion that the public perceived unmanned aircraft as having comparable risk to that of manned aircraft, and that variances in terminology had negligible impacts on the perceptions of participants. Furthermore, it was concluded that the primary concerns regarding the proliferation of unmanned systems were related to issues of privacy and misuse, and the effective neutrality of participant responses was due to a lack of information regarding the systems themselves (Clothier, et al., 2015). While the perceptions of the general public may be argued to tend towards neutrality, it remains to be seen whether this may be applied to pilots.

Central to the methodology of this study is the ability to evaluate pilot willingness to fly and willingness to fly in general. Bergstorm and McCaul (2004) established that explicit decision-making models are largely based on a foundation of logic. However, there is an affective component of risk perception that may profoundly impact one's decision-making or willingness to fly. In a study of students following the 9/11 terrorist attacks, Bergstorm and McCaul (2004) determined that worry was "the most powerful predictor" of one's willingness to fly (p. 1846). A single question regarding the emotion of worry, however, is not sufficient in determining overall willingness to fly. To this end, the Willingness to Fly scale was developed by Rice et al. (2015); it employs a scale of seven questions in order to determine the willingness to fly and was originally developed on Amazon Mechanical Turk. These questions are phrased such that they prompt consideration of matters of comfort, fear, and safety to name a few (Rice et al., 2015).

Having established the importance of the perception of risk, it is also necessary to examine the contemporary state of the safety of UASs, and the development that has already taken place in order to protect both manned aircraft, and persons and property on the ground. Cho (2014) examined numerous challenges associated with the safe integration of UASs into the NAS. With respect to UAS safety, Cho (2014) discussed comments made by the Air Line Pilots' Association that cautioned against the integration of commercial UASs due to the possible threat it may represent to both commercial and general aviation. The association cited concerns regarding the assumed increased responsibilities of aircraft traffic control, and the lack of collision avoidance systems or secondary tracking systems, such as transponders, in order to assure separation of UASs from their manned counterparts (Cho, 2014). Additionally, Cho (2014) discussed the limitations of ground stations, and the loss of direct control should the datalink – the means by which the unmanned aircraft communicates with ground stations – be lost. Similarly, Mariani (2014) discussed the technological limitations of UASs specifically with respect to their limited ability to reliably detect, sense, and avoid people, obstacles, and other aircraft. The ability of an unmanned aircraft operator to effectively see and avoid hazards is likely adversely affected by the perspective of the operator (Mariani, 2014). While the implementation of the Federal Aviation Administration's NextGen initiative is cited as a possible solution to problems relating to collision avoidance, the Automatic Dependent Surveillance-Broadcast (ADS-B) equipment requirements were, as of the date of publication, not applicable to unmanned aircraft (Mariani, 2014). While the safety of UASs has advanced significantly, the impact of such advances is marginalized by the continued perception of unmanned vehicles as an inherent threat to safety. Nevertheless, an understanding of safety is required to determine whether the perceptions of manned aircraft pilots are based on thorough assessment of the hazard, or affective skepticism founded on a limited knowledge base.

As UASs have grown in popularity, so has the need for these new systems to be regulated and integrated into the NAS. DeGarmo (2004) discussed the need to integrate UASs into the NAS and the potential complications that might arise from related regulatory processes, including providing

recommendations on matters such as unmanned pilot education, and safe and secure operating practices. Furthermore, the FAA now has regulations regarding the operation of UASs under Title 14 of the Code of Federal Regulations Part 107 with the goal of keeping operators and pilots safe while fostering efficient UAS integration into the NAS.

While strategies for the safe integration of UASs are already being implemented, and manned aircraft pilots likely already operate within airspace that is shared with operating UASs, it remains to be seen whether knowledge of the presence of an unmanned aircraft would influence flight student decision-making. The aforementioned research regarding risk perception would suggest that the declaration of the presence of a UAS would likely increase perceptions of risk and, therefore, decrease willingness to fly. Furthermore, the research that is specific to UASs does not assess pilot perceptions of UASs as a determinant and an indicator for the effectiveness of current regulations, safety improvements, and integration strategies. This study, therefore, seeks to offer an empirical basis for aviation-specific discussions on the perceptions of UASs by investigating how a pilot's willingness to fly changes as a function of the presence of an unmanned aircraft within an airspace.

5. Research question and hypothesis

Does the presence of a UAS within a given volume of airspace affect a flight student's willingness to fly either within or above that airspace?

Flight students' willingness to fly was expected to be highest with no UAS present, intermediate over airspace with a UAS, and lowest with a UAS operating within the airspace through which they are flying.

6. Methodology

Participants

The study collected responses from students who were a minimum of eighteen years old and were flight students at the Florida Institute of Technology.

Procedure and materials

No identifying information was collected to maintain participants' privacy, and the Florida Institute of Technology Institutional Review Board approved the exemption (IRB #17-035). This study used an electronic survey, created using Google Forms, which was distributed via the student email list of the College of Aeronautics, resulting in a convenience sample. Participants were given three aircraft operating scenarios: 1) the flight requires flying through airspace with no operating UAS, 2) the flight requires flying through airspace with an operating UAS, and 3) the flight requires flying over airspace with an active UAS. In each case, the volume of airspace was defined as a cylinder that had a radius of five statute miles (SM) and extended vertically to an altitude of 2,500 feet above ground level (AGL). These values were chosen to closely resemble a typical Class D airspace found around low to moderate traffic, towered airports. Participants were asked to rate their willingness to fly in these scenarios using the willingness to fly scale developed by Rice et al. (2015). At the conclusion of the survey, participants were asked demographic questions, as well as the flight course in which they are currently enrolled, which was viewed as a proxy for experience level.

Data collection and analysis

The data was exported from Google Forms to Microsoft Excel. Descriptive statistics were calculated in Excel and inferential statistics with SPSS v. 23. Cronbach's alpha was used to assess internal reliability, and a repeated measures ANOVA was conducted using the average willingness to fly for each scenario.

7. Results

Demographics

The accessible population comprised flight students of the Florida Institute of Technology. Of the survey population (N = 160), 43 responses were attained for a response rate of 26.9%. The age of respondents ranged from 18 to 56 with an average age of 21.6 years and a standard deviation of 5.9. Respondents included 27 domestic students, one of whom was from Puerto Rico, and 16 international students consisting of two students from Barbados, two from Cayman Islands, one from The Kingdom of the Netherlands, one from Switzerland, one from Ecuador, one from Nigeria, six from The Republic of Trinidad and Tobago, one from Jamaica, and one from Jordan. Respondents selected either their current flight course or the course in which they were last enrolled as a proxy for experience. Of the responses collected, there were 10 private pilot certificate holders or candidates, eight instrument rating holders or candidates, one commercial single-engine initial certificate holder or candidate, four commercial single-engine add-on certificate holders or candidates, six commercial multi-engine initial certificate holders or candidates, 10 certified flight instructor certificate holders or candidates, one certified flight instructor-instrument certificate holder or candidate, and three whose responses did not fall into the categories listed above. Although the sample was a convenience sample, respondents were appropriately distributed across flight courses in order to represent the FIT student pilot population.

Descriptive statistics

Quantitative analysis of the survey results was enabled through the coding of the Likert scale responses from negative two to positive two where “strongly disagree” equated to negative two, “disagree” equated to negative one, “neutral” equated to zero, “agree” equated to positive one, and “strongly agree” equated to positive two. In order to determine the consistency of the responses by participants to the willingness to fly scale within a given scenario, Cronbach’s alpha was calculated. Cronbach’s alpha for scenario one, scenario two, and scenario three were 0.98, 0.96, and 0.97 respectively. These indicate very consistent responses; therefore, for further calculations, the averages of the willingness to fly scale responses were used for each scenario.

Table 1 shows the descriptive statistics for each flight scenario where scenario one refers to flight within the airspace volume where there is no UAS present, scenario two refers to flight within the airspace volume in which there is also at least one operating UAS, and scenario three refers to flight over the airspace in which there is at least one operating UAS. The average willingness to fly was highest without an active UAS, and lowest in airspace with a UAS.

Table 1. Descriptive statistics for each willingness to fly scenario

Scenario	Mean	Mode	Median	Standard Deviation
1	1.27	2	1.71	0.87
2	0.20	0	0.29	0.99
3	0.89	2	1	0.87

Figure 1 depicts the willingness to fly as a function of the presence of an unmanned aircraft within a volume of airspace that a flight student must either fly through or over. Scenario 1, in which students were asked to fly through airspace containing no active UAS, had the highest willingness to fly; scenario 3, in which students were asked to fly over the airspace containing an active UAS, illustrated a lesser willingness to fly; and scenario 2, in which students were asked to fly through the airspace containing an active UAS, indicated the lowest willingness to fly.

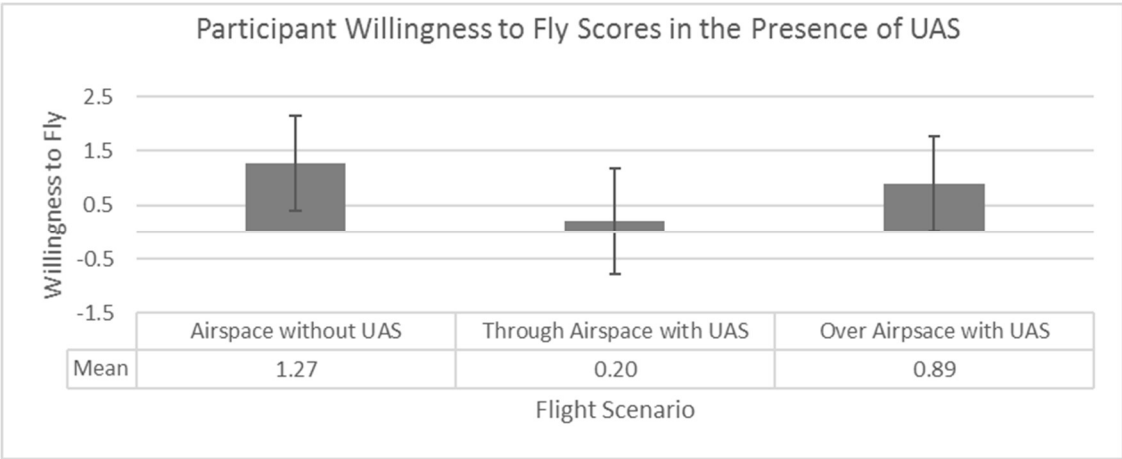

Figure 1: Participant willingness to fly scores in the presence of UAS

Inferential statistics

Assuming a lack of sphericity, a 3x1 repeated measures ANOVA using a Greenhouse-Geisser correction for sphericity determined that willingness to fly varied significantly with the presence of a UAS ($F(1.97, 82.92) = 28.45$, $p < 0.005$). The partial eta squared was 0.55, which is a medium effect size.

8. Discussion

The objective of this research was to determine the impact of UAS presence on collegiate flight students' willingness to fly. In order to statistically evaluate the effect of the presence of a UAS, a within-subjects design presented all participants with the same three distinct flight scenarios. Having analyzed the data as discussed above, it was determined that collegiate flight students' willingness to fly varied with statistical significance with the presence of at least one UAS within a volume of airspace in which the manned aircraft must either fly over or fly through, with the lowest willingness to fly occurring when required to fly in airspace with an active UAS.

While the control scenario, no UAS present, suggested a general willingness to fly within the empty airspace volume, the data show several low responses, which indicated an unwillingness to fly within the empty airspace volume. This may be attributed to the affect heuristic of Slovic and Peters (2006), which established the correlation between the presentation of information and the effect of that information on the survey participants. Despite the commonality of the airspace volume, the perception of the size of that volume may have been affected by the lack of an association with a Class D airspace. Additionally, the possibility exists that the outlying respondents maintained a general nervousness or unwillingness to fly regardless of the airspace dimensions.

The results of the occupied airspace overflight scenario illustrated reduced willingness to fly when compared to the control, and the results of the airspace co-occupancy scenario exhibited a further decrease in wiliness to fly when compared to the overflight scenario. It should be noted that the location of the unmanned aircraft relative to the manned aircraft was never specified. As such, while the regulations outlined in Title 14 of the Code of Federal Regulations Part 107 restricted the maximum altitude at which an unmanned aircraft can be operated, participants were allowed to answer either without knowledge of the regulation, or to assume that an unmanned aircraft operator would operate their aircraft at any point in the volume despite the regulation.

Comparisons of the results across the three survey scenarios supported the research hypothesis. It can be concluded that flight student willingness to fly decreases when the student is meant to fly over a volume of airspace that contains a UAS. Willingness to fly is further decreased when students are asked

to fly through the airspace volume containing an unmanned aircraft. While this variation in willingness to fly may be attributed to logical assessments of risk, it is also likely that pilot perceptions of unmanned aircraft vary due to the affective component of risk assessment established by Slovic and Peters (2006). While the willingness to fly scale does not determine the cause of the decrease in willingness to fly, the observed statistical differences may be attributed to perceived consequences of a crash or a near-miss, the lack of knowledge of UASs, the lack of knowledge of the regulations that govern the certification and operation of unmanned aircraft, and the lack of control that a manned aircraft pilot has in mitigating adverse unmanned aircraft encounters. While a significant statistical variance between scenarios is observed, it should be noted that there is no point at which the average scenario response suggests an unwillingness to fly, rather a decrease in willingness to fly.

Future Research

While the findings of the study were expected based on the aforementioned background research, there are several limitations worth noting. The Willingness to Fly scale was tested for validity and reliability for use on Amazon Mechanical Turk, not student pilots. The very high Cronbach's alpha calculations, however, support the scale producing consistent responses internally with the pilot population. While the Willingness to Fly scale was able to provide data for the establishment of a relationship between the presence of a UAS and collegiate flight students' willingness to fly, it can not necessarily be used for determining the causal factors behind the variance from scenario to scenario. Additionally, the recruitment strategy necessitated the acceptance that some of the flight students may have trained at other flight schools or under either or both Part 141 and Part 61.

Furthermore, the airspace volume, representative of a small volume of controlled airspace, is only effective at establishing willingness to fly given the specified dimensions. As such, future studies should seek to determine willingness to fly as a function of the size of the airspace volume or proximity to the UAS. Additionally, future researchers should address whether pilot knowledge of UASs has any effect on the willingness of a pilot to share airspace with an unmanned aircraft. Finally, the results of the survey may have been influenced by the presentation of the flight scenarios or the lack of an actual requirement to fly each scenario. Consistent with the assertion that risk perception may be manipulated through the presentation of information, future studies should randomize the order in which the flight scenarios are presented with each participant.

Conclusion

Flight student willingness to fly may be asserted to vary depending on whether that pilot is asked to operate their aircraft either over or through a volume of airspace that is shared with a UAS. While consistent with studies of risk perception, the results showed what is, in effect, a preference by flight students that differs from the reality of small UAS operation within the NAS. While the findings of this study represent a significant starting point, future researchers are urged to investigate a similar hypothesis with a sample population of more experienced pilots, and to evaluate the causal factors that lead to the variance in willingness to fly.

9. Acknowledgements

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Why Are There So Few Women in STEM?

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Abstract

Women are significantly underrepresented in Science, Technology, Engineering, and Mathematics (STEM) in the US and around the world. Although the number of women in the United States pursuing engineering degrees is growing, the number of women entering the workforce long term as practicing engineers is still drastically stark. The underutilization of women in our country in the advancement of science and technology, may slow economic growth. We argue that women are needed in STEM to ensure a diverse meeting of the minds where creative and effective solutions can arise. There is a plethora of research on why there are so few women in STEM careers. The majority of this research focuses on these two main themes: first that girls do not find interest in these types of careers to begin with and second that once women enter the engineering field they leave at a higher rate than men. Several theories address the etiology of these issues including gender stereotype sand biases, negative work experiences, and self-doubt. This paper summarizes research that examines why there are fewer women pursuing and staying in engineering and other STEM fields.

1. Problem overview

Despite girls and boys having equivalent math and science achievement upon graduating high school, the number of girls that enroll in engineering or computing programs in college is much lower. The small fraction of girls that do enroll in these programs becomes even smaller by college graduation, and by the time women enter the workforce in engineering, they are greatly underrepresented (AAUW, 2015).

1.1. Higher education

The number of women earning engineering degrees has grown slowly over the past three decades. In 1985, 15% of engineering degrees were earned by women. Twenty years later, in 2005, that number had grown to 22% (AAUW, 2015). In 2015, the number of women earning bachelor degrees in engineering had dropped down to 20% (Gutierrez, Paulosky, Aguinaldo, & Gerhart, 2017). In 1984 and 1985, women earned 37% of the bachelor's degrees in computing, but unfortunately that number began declining after 1985 and by 2013 the percentage was down to 18% (AAUW , 2015). This disparity between men and women graduating from engineering and computing programs is not caused by a lack of women's interest in achieving higher education. In fact, women have outnumbered men in undergraduate education since 1982, and are earning approximately 57% of all bachelor degrees since the late 1990s (National Science Board, 2018).

1.2. Workforce

While 20% of women earn engineering degrees, the number that actually ends up in the engineering workforce is much lower (National Science Foundation, 2015). Women made up only 12% of engineers

in the workforce in 2013 (AAUW, 2015), and this percentage has only increased a few percent in the past 30 years as can be seen in Figure 1. The Figure also shows that the percentage of women in all Science and Engineering occupations have remained relatively stable with only a slight increase. The distribution of women also varies across engineering fields. In mechanical and electrical engineering fields, women earned 13.2% and 12.5% of engineering degrees, respectively, whereas in biomedical engineering they earned 40.9% of the degrees in 2015 (Gutierrez, C., Paulosky, M., Aguinaldo, A., & Gerhart, J. 2017). It is theorized that women are drawn to professions that improve the lives of others, which can explain the higher number of women in biomedical engineering compared to those engineering disciplines where the humanitarian component of engineering is less obvious.

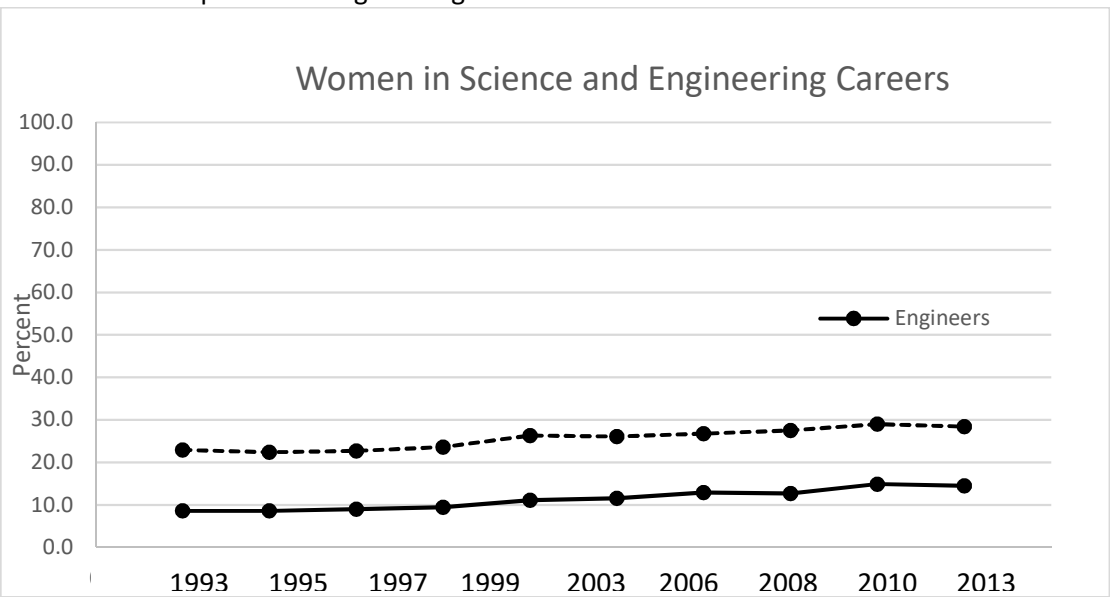

Figure 1. Women in Science and Engineering Careers (National Science Foundation (1993-2013) & the National Survey of College Graduates (2015) as cited in the National Science Board, 2018)

1.3. Retention

Once women begin careers in engineering and computing they are much less likely to remain in those fields than men. After 12 years into a woman's career in engineering or computing, 50% have left their careers (AAUW, 2015). The majority of women who leave their engineering careers attribute their decisions to unfavorable work environment and lack of advancement. Only about a quarter of female engineers leave to stay home with children or family (Fouad and Singh, 2011). The reasons women leave the field at a higher rate than men is explored further in Section 2 herein.

2. Causes

It is known that social conditioning is one of the reasons why women do not pursue engineering and that an unwelcoming work environment is one of the reasons they leave at a higher rate than men. These causes of low female participation are discussed in the following sections.

2.1. Social conditioning from an early age

Females are socially conditioned to think they are different from men and that they have different professional options available to them. This social conditioning includes gender biases that are both explicit (conscious) and implicit (unconscious). For example, an explicit bias may be that you hire a male engineer rather than a female engineer with similar credentials because you think that the male engineer

will better fit in with the other males already on your team. An implicit bias can be that a teacher more often calls on male than female students in mathematics and science classes without realizing this because unconsciously the teacher may think that males are better in STEM subjects. According to Greenwald, Poehlman et al., (2009), implicit bias is more widespread and is a higher predicting factor for behavior than explicit bias (as cited in AAUW, 2015). The gender bias that females have less competency in mathematics, science, and technical fields has been heavily researched. One study by Cvencek, Meltzoff et al., 2011 found that children start to associate competence in math with masculine qualities by the age of seven (as cited in AAUW, 2015). This is likely due to students internalizing these gender implicit biases from their interactions and experiences with parents, teachers, and media (Cvencek & Meltzoff, 2012). A longitudinal study by Robinson-Cimpian and colleagues (2016) examined teacher perception of children's math ability and followed students' math achievement as they progressed in early education. This study found that, after controlling for children's prior math performance and classroom behavior, teachers' ratings of children's math ability were consistently higher for boys than for girls from Kindergarten through 5th grade. The study also found a steadily increasing gap in the math performance between boys and girls, with boys consistently performing better from 1st through 5th grade. Finally the results demonstrated that these differences in gains between boys and girls were largely explained by teachers' perceptions of math ability. Children encounter these types of gender biases in many different forms across society through television, movies, magazines, advertising, clothing, etc. One example of this can be found in the form of T-shirts designed for young girls with slogans like "Allergic to Algebra", "I'm too pretty to do math", or "I'm too pretty to do my homework so my brother has to do it for me". Social messaging like this can contribute to spreading the gender bias that females are less competent in mathematics. These biases may then become self-fulfilling prophecies for girls as they grow up.

There has been a great deal of research performed on one form of implicit bias, stereotype threat. Stereotype threat occurs when someone who belongs to a stereotyped group is performing a task related to that stereotype. A study by Cadaret, Hartung, Subich, & Weigold (2017) showed that female students would perform worse on a test if they were subjected to sexist remarks or even reminded of their own gender, referred to as gender priming, prior to taking the test. It was found that merely being asked to check a gender box prior to taking a test on a male dominated subject resulted in poorer female performance in comparison to males and to females who did not experience gender priming. Taken together, the research reviewed here suggests that implicit bias related to stereotyped beliefs about the differences in math performance between girls and boys may influence increasing gaps. These gaps may contribute to lower levels of self-selection into STEM areas in the long-term. The next section will examine forms of explicit bias females may experience in the workplace.

2.2. Unwelcoming work environment

According to a survey by Fouad & Singh (2011) of over 3,700 women who earned engineering degrees almost 50% left due to difficult work environments, including excessive travel, difficulty advancing, and poor compensation. Approximately 30% left engineering due to organizational climate, including lack of flexibility, unwelcoming culture, and unfavorable management. Approximately 25% of female engineers left the field to care for children or other family members (Fouad & Singh, 2011).

As outlined above, the main reason women leave their professions in STEM fields is related to an unfavorable workplace environment. Settles, Cortina, Buchanan, & Miner argued that negative workplace climate factors such as gender discrimination and sexual harassment are the factors most likely to affect job satisfaction amongst women in academic science professions (as cited in AAUW, 2015).

Women face gender discrimination in several ways in male-dominated fields. Women in industry and

in academia report having to work harder to prove themselves to earn respect compared to white men. In industry, 61% of women vs 35% of white men reported they have to prove themselves repeatedly to get the same levels of respect and recognition as their colleagues (Williams, Li, Rincon, & Finn, 2016). According to a study by the National Academy of Sciences (2013), in academia, only 52% of white men responded affirmatively to the statement "I need to work harder to be perceived as a legitimate scholar", while 67% of white women did, and a much higher 79% of women of color responded affirmatively (as cited in AAUW, 2015). While only 9% of white men had been mistaken for administrative staff or technicians, 45% of women surveyed reported that experience (Williams et al., 2016). Lyness & Heilman (2006) (cited in AAUW 2015) found that women in manager positions need higher performance ratings than men in the same positions to be promoted.

When men who are managers hold views of benevolent sexism (the view that women need to be protected) they tend to assign less challenging and high-risk tasks to women (King et. al, 2012). This trend can hinder women from advancing in their careers because challenging assignments that require learning new skills lead to advancement opportunities (Bray & Howard, 1983). Besides being tasked with less challenging assignments, women who work in benevolently sexist environments may begin to believe that they themselves need to be protected from challenging situations and that they are less capable of performing well in these situations. Unfortunately, sexism in the workplace extends beyond benevolent intentions, with 63% of women in the private engineering sector reporting having been sexually harassed at work (AAUW, 2015).

Another reason that women leave STEM fields particularly in engineering and computing professions may result from what is referred to as a "culture of disengagement." This disengagement reflects women's loss of interest in their careers due to the lack of clear societal purpose for the work they are doing. Research shows that women become and remain interested in engineering when they are engaged in the bettering of society or humanitarian type work (Konrad et al., 2000). For example, when the contribution to society is obvious, as in for example Biomedical Engineering where medical solutions are developed, more women tend to choose that discipline than disciplines such as nuclear engineering, where societal benefits may be less obvious. As mentioned previously, in Biomedical Engineering, where there is a clear connection to a societal cause, women make up 40.9% of degree earners (Gutierrez, C., Paulosky, M., Aguinaldo, A., & Gerhart, J, 2017).

3. Why a solution is important

The underrepresentation of women earning degrees in engineering fields contributes to discrepancies in opportunity, income, and social mobility for women. Representation for women matters not only to the betterment of their own lives, but contributes to the quality of life of the entire community, economy, country, and world. When 50% of the population is left out of decision-making and major problem-solving opportunities, the opportunity for the inclusion of a diversity of ideas and solutions is lost. To identify the most pertinent problems and the most successful solutions, a diverse group of people from all backgrounds must be involved, because a diverse group of people are more likely to provide a variety of perspectives and understand the needs of different people and communities and have a variety of experiences that can help contribute to better solutions.

It is important, however, to specify what forms of diversity contribute most to improving performance outcomes on teams and in workplaces. It may not be enough to simply increase the numbers of women in male dominated STEM fields, referred to as increasing demographic diversity. One study found that increasing the representation of women alone did not improve performance outcomes in corporate settings (Joshi and Roh, 2009). Instead, research suggests that performance outcomes are most improved if members of the team are well-integrated. In other words, the degree to which those demographically diverse teams work together and the perspectives of all team members are included and respected in a

non-hierarchical fashion contributes most to positive performance outcomes. Members of the team must feel comfortable to express their viewpoints and must be respected by peers to fully reach the benefits leading to intellectual diversity, creativity, and ultimately better solutions (Smith-Doerr 2017).

Increasing representation and full integration of women in engineering is vital to ensure a diverse meeting of the minds where creative and effective solutions can arise. Women bring different experiences than men and can contribute differently in a company. Their inclusion and the respect of their perspectives is vital for our society and companies to stay competitive and to evolve with a globalizing world. With the inclusion and full integration of women and other minorities, companies are more likely to develop solutions that are beneficial to a broader group of society, which benefits society and also the profitability of the company.

4. Conclusion

In conclusion, the number of women who pursue degrees in engineering is much lower than men, and the ratio of women to men in engineering drops even further as women progress through degree completion and into engineering careers. There is an underutilization of women in engineering that can likely be attributed to social conditioning of gender biases and unfavorable working conditions that include gender discrimination, lack of advancement opportunities, and poor-work life balance for mothers. Representation for women matters to empower their lives, and also to raise the quality of life of the entire community, economy, country, and world. It is time to change the organizational climate of education systems and workplaces to encourage more women to pursue engineering and advance in the field, and to welcome them in the field by respecting their opinions as equal to that of men's.

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Outreach Project Aimed at Increasing Gender Diversity in Engineering

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Abstract

Based upon a low percentage of women obtaining college level education and establishing careers in the Science, Technology, Engineering, and Mathematics (STEM) fields, the University of North Florida (UNF) aims to engage precollege girls through an outreach program. This program is designed to foster positive role models and provide a course correction to the embedded stereotypes that influence our youth. Presentations, demonstration models, and design activities were devised for elementary school children. Outreach has been shown to be capable of upsetting biases and providing encouragement to those interested, but historically ostracized, in the STEM fields. This paper discusses some of the gender statistics in engineering and provides details of the outreach program developed by The Center for the Advancement of Women in Engineering (CAWE).

1. Introduction

There is a lack of diversity in STEM fields, including gender diversity. Only 24% of those employed in STEM careers are women (US Department of Commerce, 2017). This paper discusses an outreach project initiated to address the lack of diversity specifically in engineering. The percentage of women employed in engineering is particularly low, at only 14% (US Department of Commerce, 2017), which is in stark contrast to the general employment of women, which is at 47% (see Figure 1).

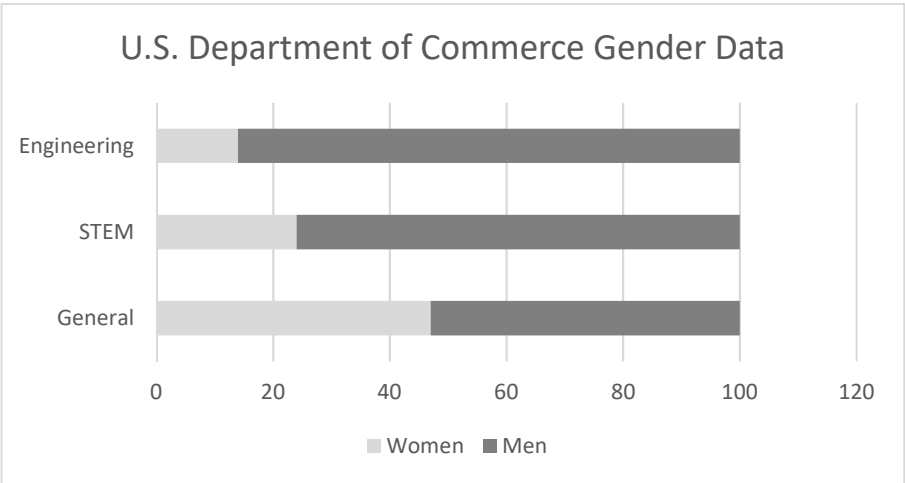

Figure 1: The representation of women in STEM, engineering, and general employment (US Department of Commerce, 2017)

As seen in Table 1, some fields have shown a growth in the percentage of women since 2000 while others, specifically Computer Science and Mathematics, have decreased. The rate of increase of female inclusion in Engineering is barely discernible, with only 1% increase from 2000 to 2015. Women are represented in the Physical and Life Sciences at 43%, a rate similar to general employment rates for women, but still lower by nearly 5% (US Department of Commerce, 2017).

We argue that engineering and other STEM fields must improve gender diversity to remain globally competitive for two primary reasons. First, there is a shortage of engineers in this country and the gap between available engineering jobs and the number of engineering graduates is expected to grow. That is why there is a strong effort by the federal as well as state governments to encourage students to pursue STEM fields, including engineering. One way to increase the number of students pursuing engineering is to recruit among women and girls, as women are severely underrepresented in the engineering workforce. Second, drawing upon underrepresented groups has the potential to not only increase demographic diversity, but can lead to an increase in diverse thinking. Diverse thinking may contribute to identifying the most crucial problems and developing the best solutions. As indicated above, women are grossly underrepresented in STEM, and particularly in Engineering. Hence, their viewpoints and unique experiences have not been represented in determining the direction of companies, societies, and solutions to engineering problems.

Table 1: Total Percentage of Women in STEM Careers

	2000	2009	2015
STEM Total	24%	24%	24%
Computer Science and Math	30%	27%	26%
Engineering	13%	14%	14%
Physical and Life Sciences	36%	40%	43%
STEM Managers	23%	25%	25%

A breakdown of data from the US Department of Commerce displaying percentage of female employment in some STEM fields (Women in STEM: Gender Gap to Innovation, 2011; Women in STEM: 2017 Update, 2017)

The low numbers of women in STEM fields may derive from systematic gender biases that steer females away at an early age. Research demonstrates, for example, that girls, by the age of six, experience stereotyping that they are intellectually less capable than their male counterparts, and in turn, girls begin to avoid activities they perceive to be for those who are “smart” (Bian, Leslie, & Cimpian, 2017). The effects are likely long-term and contribute to career choices and trajectories of women more generally. Outreach programs may provide a course correction to these gender biases and improve gender diversity in STEM fields like engineering. In one study, findings showed that a three year long after-school outreach high school program in which high achieving female students explored engineering, worked on an engineering design project. Their involvement in college mentoring in addition to being part of a pre-engineering community increased young females’ interest in Engineering (Bystydzienski et al. 2015). In the beginning of the program only 18% of the participants considered pursuing engineering in college, whereas 51 % of the participants considered this during the third year of the outreach program. The article also noted outreach was not enough to retain the women in the engineering path. Women of low-income backgrounds were afraid that they wouldn’t make the necessary grades in engineering to keep their scholarships, and therefore chose a different major. The study suggests that mentors, counselors, and financial resource education are also needed to help low-income women pursue engineering.

At the University of North Florida (UNF), diversity is one of the six university-wide values. The need for diversity and inclusion is recognized within the School of Engineering at UNF as well; and to help

improve the recruitment, retention, and advancement of women in engineering, UNF established The Center for the Advancement of Women in Engineering (CAWE). The following section will discuss an outreach program developed by CAWE for the purpose of recruiting more females into engineering.

2. Outreach Program

To help increase the participation of women in engineering an outreach program aimed toward young children was developed to provide education about what engineering is and that engineering is a career suitable for males and females. The outreach program consisted of presentations, demonstration models, and design activities for elementary school children and was delivered by engineering college students. The goal of the outreach program was to educate children about what engineering is and how engineering contributes to society; and to provide program participants with hands-on engineering experiences as well as female role models in engineering. An overview of the research suggests that females may be more attracted to fields in which the societal benefits are readily apparent. Discussion of stereotypes and how they affect girls may begin to counter the implicit and explicit biases young girls experience and that pressure them to avoid STEM fields. Engaging girls in an engineering project may contribute to their self-perception as capable of engaging in such activities. And, creating a tangible relation to the field through female role models may help spark memorable and influential interactions leading to a possible interest in working in the field.

In regard to the notion that women are more attracted to professional fields in which the societal benefits are readily apparent, research suggests that more women pursue careers in biomedical engineering where the link of helping people is more evident than it may be in other subfields of engineering, such as electrical engineering. In 2015, women earned 40.9% of degrees in biomedical engineering, whereas women earned only 12.5% of the electrical engineering degrees (Gutierrez, C., Paulosky, M., Aguinaldo, A., & Gerhart, J. 2017). Thus, the outreach program developed emphasizes the societal impact of engineering, with one component of the program being a biomechanical engineering project. The outreach program provides a perspective on the humanitarian aspects of engineering rather than focusing on the advancement of performance or technology without the human element.

To help show that engineering helps humanity; the outreach program uses a biomechanical engineering project as a component of the outreach project. This component consists of a demonstration model and a design activity for the students. The demonstration tool is a mechanical hand model that demonstrates biomedical applications in engineering and some basic mechanical principles that govern the hand, as seen in Figure 2. Tension, moment arms, and force are demonstrated. Students are then encouraged to design and build their own hand model using provided supplies.

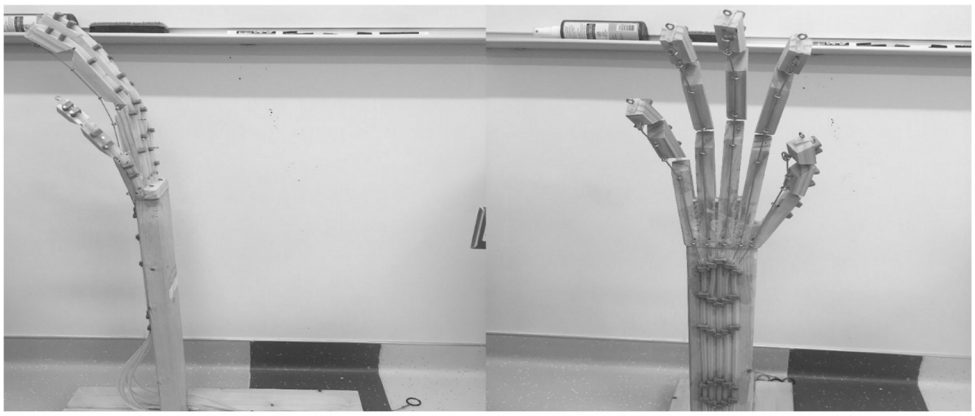

Figure 2: Model Hand for Demonstration. The model hand simulates the opening and closing of the hand using strings to represent the tendons.

3. Conclusion

Women are strongly underrepresented in engineering. In working towards more gender diversity in the field, outreach programs are developed which help educate children about what engineering is, how it is a humanitarian profession, and how the profession is suitable to both genders. UNF's outreach to the surrounding area is expected to create an influx of women working in the field, which can help reduce the bias in engineering and other STEM fields. The inclusion of both girls and boys in the outreach program is also important as boys too need to understand that women are suitable for careers in engineering and STEM; otherwise young women will enter a field where the attitude may remain that they do not belong. Considering this, female role models are important for both female and male potential students. Increasing the number of female role models in engineering is expected to, over time, help increase the number of women choosing to study engineering, and hence more engineering women entering the field.

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Addressing the Sustainability and Engineering Goals by Evaluating the Gender Inequality in the Workplace

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Abstract

With a concerning number of women leaving the engineering field in recent years, the research team sought to discover the reason with the ultimate goal of creating insights based on the information gathered. The research team collected and analyzed the perceptions of women and men, of whom are either studying or practicing engineering. Approximately 200 students and 50 professionals were surveyed, with the majority of the students surveyed attending UCF, while the professionals were from around the world. From the survey data, we were able to conclude that a higher percentage of women, both at the college and professional level, feel as though they are at a disadvantage in the engineering environment as compared to their male counterparts. Without achieving gender equality in the classroom and workplace, female contributions remain deemphasized, and neither the Sustainable Development Goals set into place by the UN nor the Engineering Grand Challenges would be fully addressed in the most effective and timely manner.

1. Introduction

As infrastructural, social, and technological advancements continue to evolve at an unprecedented pace, we need the engineering industry to be comprised of a diverse population of people who innovate with sustainability and ethics in mind. Therefore, without an equitable representation of women in the engineering field, we cannot hope to meet the challenges posed by today's world. Even though the stigma towards women who pursue engineering fields has lessened as time progresses, the problem of women leaving engineering fields is becoming ever more apparent. If women are leaving at an unsustainable rate, then it becomes critical to examine the causes. By gathering perceptions and information from a diverse and wide sample of both men and women engineers, we can draw meaningful relationships between gender and perception of engineering condition. All of this put us one step closer to solving the problem of the exodus of women in engineering. By understanding why women are leaving the engineering profession, the opportunity for change arises for women in the engineering world, whether it be in the university or in the workplace. Current initiatives to make engineering more inclusive and gender equal can be assessed and insights can be made the transition from engineering to college to the professional arena. Ultimately, by keeping the retention of women high in stem we can move closer to gender equality all while putting us in a better position to meet the Grand Challenges in the Engineering world.

2. Significance of the research

In a world with a rapidly increasing population, development rate, and need for innovation, the engineering profession has never been so critical to human society. Thus, the demographic makeup and average workplace environment of the engineering profession are important to keep monitored. By having an open, fair, and happy professional environment, our engineers can be in a better position to tackle the complex and multifaceted problems of today and the near future. One of the components of a fair, open and happy workplace environment is gender equality. If women are feeling as though their credibility is wrongfully being called into question at times or that their contributions to their business are being undervalued, then it is difficult for the workplace environment to be a completely productive space. Therefore, to determine the state of gender equality in the professional workplace, the direct opinions of the students and workers who inhabit it need to be collected. By hearing directly from engineers who are at various points in their professional careers, we can get the most transparent look at the engineering industry. Then, new insights can make from the organized information used to make suggestions for improvement. In addition, the perspectives of the engineers themselves surely impact their work and ideas. As the opinions of women continue underrepresented, we as a society miss out on potentially future-altering innovations and insights. If we hope to achieve the Sustainable Development Goals by 2030, groundbreaking innovations need to be made sooner rather than later. Furthermore, with changing geopolitical systems still proving to be volatile, science and engineering are important systems that could move the planet towards peace and prosperity.

3. Literature review

For generations, engineers have been one of the greatest proponents of growth in human society. However, throughout these generations, one underlying fact haunts the community. The engineering field is extremely dominated by men and has a severe underrepresentation of women. What we seek to analyze is the cause for the absence of women in the engineering field, and whether the problem lies within the workplace, the classroom, or both. We also seek to tie this issue to the United Nation's Sustainable Development Goals [SDG's] that were set in place to prospectively enhance our world in the long term. The SDG's that we addressed directly were those involving gender equality, reduced inequalities, quality education, and decent work and economic growth. However, to start uncovering the information behind the absence, it was essential to find out more about the topic through some secondary research.

Despite the general lack of women in the engineering profession, there has been an increase in female engineers over the previous years. According to Kahn and Ginther (2015), "Women are an increasing percentage of Bachelors in Engineering (BSEs) graduates—rising from 1% in 1970 to 20% in the 2000s". More women are developing an interest in the engineering, but they still only make up a relatively small of a portion of the new population of engineers. Many women are discouraged from entering the engineering field for a variety of reasons. Some of these reasons, as explained by Prives (2016), could be the pressure of being a female in a male-dominated classroom and the community pressure that follows with straying from the norm.

Although there is a large problem in getting women into the engineering field, there is an even bigger one keeping them there. One of the most prominent reasons for women leaving the field is the dominance of the workplace by overly masculine behavior. In (2016, Oct 05), it was stated that "Female engineers are leaving an already male-dominated engineering field due to a culture that does not take them seriously". Rubineau continued, discussing the fact that many of the women experience blatant gender bias and are relegated to more secretarial duties. With these immensely unjustified actions prevalent in the common engineering workplace, it's no surprise that women would want to leave the

field. Zywicki (2016), explained that the reason women are leaving the field is that there is a "lack of confidence of company direction". According to their research, it was discovered that women were leaving the companies that did not consider gender to be diversity. This finding is yet another instance of females being undermined in the workplace, which inevitably contributes to them departing their careers. Trends like this show that there is a significant deficiency of the awareness and respect of the female community in the field, which is a problem that can be further evaluated using SDG's (gender equality and reducing inequalities). Along with the gender-based inequality of the engineering society, many women face hardships that most men in the profession don't have to face. Xu (2017) explains that "women experience clear disadvantages in salary and employment status". So although women already face hardships in the environment as an engineer, they also suffer from lower wages and fewer opportunities than their male counterparts.

There are several other root causes as to why women are leaving engineering. One of these is the major stereotype associated with being a woman in this field. According to (Beasley and Fischer, 2012), many women are leaving the engineering career due to the stereotype that labels them as being inept in subjects associated with math and science. This stigma lowers women's confidence level and decreases their performance, directly hindering the SDG involving decent work and economic growth. Women are also leaving their careers as engineers because they start their own families. Kahn and Ginther (2015), claimed that most of the women leaving engineering are due to them having kids. The workplace must become more accommodating for mothers so that they can continue to contribute while bearing their personal responsibilities.

After seeing the reasons why there are an absence and depletion of women from the engineering profession, one may ask how to fix this problem. Many have tried to correct the problem with some successes and many failures. Sharp, Franzway, Mills, and Gill (2012), studied engineering companies to find out what they had done to include more women in the workplace. With upsetting results, they found that it was too difficult to incorporate diversity policies because the underlying gender politics were too prevalent. This study was actively trying to seek out areas where there had been reduced inequalities and gender equality, which would have been beneficial toward their respective SDG's, but also showed that this is a much more difficult goal than expected. However, there have been many situations where methods have been used to inspire women to join the engineering field and stay there. One such method is the Women's Alliance for Knowledge Exchange [WAKE] in Prives (2016), piece created by Trish Tierney and Heather Ramsey which basically serves as a program to inspire and keep women motivated when it comes to their profession. Another method to inspire women was brought up by (Heilbronner, 2013) when discussing that self-efficacy is a large reason for the absence of women. He utilized some of Dweck and Halpern's research by saying that teachers may help talented girls develop higher self-efficacy by providing specific praise directed toward effort rather than ability, teaching that abilities can be developed over time, and through teaching realistic goal setting (Dweck, 2007; Halpern et al., 2007). This would be a strategy implemented during pre-college schooling to get the children interested from a young age. This strategy could be tied to the SDG involving quality education. The system can implement these steps to better the schooling of a pre-college student while encouraging them to pursue engineering careers. It also incorporates the SDG for decent work and economic growth as the self-efficacy developed by the women will enhance their work performance and keep them interested in engineering.

As it can be seen, there is a very large problem in the engineering industry when it comes to a lack of women. Without women, the UN's SDG's would never be able to reach fruition, and we would continue to struggle along. There is a large majority of men within the profession, and many women choose not to stay due to the culture within it. But there are ways to approach this, and our goal in this research is to seek these elements out in further detail.

4. Methodology

With no shortage of engineering challenges and an expansion of the engineering field, diverse perspectives in the engineering profession should be emphasized. Therefore, these challenges would not be met if women are leaving the engineering field at an unsustainable rate. Historically, women have been discouraged from pursuing a career in the engineering field, however, in recent years many women have pursued the engineering profession but have been faced with hostile work environments and biases that call their credentials and skills into question regardless of their qualifications or experience. So, it follows that a shift in the atmosphere of the engineering workplace would promote gender equality. The key to us then is not only encouraging women to enter the engineering field but to see that they stay in the field and occupy fulfilling and meaningful positions within the workplace. Therefore, it is key to gauge the awareness of the affected people as well as the overall climate surrounding these issues. In this study, a survey including college students majoring in engineering as well as professionals within the professional discipline was conducted; all while taking an especially close look at female engineering professionals and female engineering students. The perceived comfort and support level for women in the engineering classroom and professional arena were measured. Measurement of such variables enhanced the understanding of the areas of engineering education and training that need to be improved upon. Through this process, the engineering hurdles that next generation of engineers would face could be effectively tackled.

In order to draw conclusions based on the current climate of engineers and the experiences of women engineers, the opinions of fellow students and professionals in the engineering workplace were collected. We believe that survey was be the best method to collect this data. Performing surveys on perceived attitudes towards women in the classroom or workplace, work/personal life balance, likelihood to stay in the field, and other issues, has led to the understand how the community sees them. Therefore, this study aims to examine the general public's awareness of the shortage and exodus of women in the engineering field as well as the feelings and attitude of the people in the field. Within this survey, information about the comfort of students in their daily classroom interactions, including peer-to-peer as well as student-professor/TA interactions were gathered. Additionally, people's feelings as though there are any possible advantages or disadvantages that are associated with their gender, specifically for a female engineering student or professional were tested. Looking at the professional side, information about workplace comfort level (among peers and superiors), perceived likelihood of promotion, the effectiveness of vacation and maternity leave programs, and effectiveness of mentorship programs were collected. In order to differentiate female engineers to a control group, the results of women in the engineering field were compared to their male counterparts.

To effectively conduct these surveys, a broad enough sample size was selected. Luckily, UCF is home to a large and diverse pool of people, including connections to professional societies and associations. The focus was on women engineers at UCF and their responses to topics regarding their environments while the information collected from men was used to provide a contrasting perspective. The demographic questions include gender, major, graduation year, age, ethnicity, marital status, household income, hours worked per week, and education level. The information garnered from these demographic questions was powerful because it allowed us to form insights about more factors than just gender. Also, the compound advantages or disparities that come with the intersectionality were also considered and examined. Perhaps being a specific race, gender, or age results in a significantly different subjective experience than another. Additionally, more detailed and useful conclusions based on income, education level, and hours worked a week were obtained. The effect of education level on the issues at hand and the evaluation of the similarities or differences among the engineering sub-fields were also identified. Furthermore, the age gradient of the sample was utilized to determine if these issues have changed over time, as a result of collecting age and graduation years. Furthermore,

connections regarding the difference between the engineering environment in college and in the workplace were also drawn. Such information were used to evaluate whether the problem lies in the classroom or workplace, and propose new programs to increase the gender equality in these environments. If both environments show negative results, then perhaps we must act earlier, and direct our efforts to promote equality while encouraging women to pursue engineering throughout the entirety of their schooling.

In order to cause meaningful and lasting changes within the engineering industry, an understanding of the factors that play into the advantages or disadvantages that women and minority groups face within the engineering field was reached. With the insights made about women in engineering, some methods that could be used to advance engineering as well as S.T.E.M. education, attract more females to pursue an engineering education, and encourage them to stick with the engineering field and secure valued jobs in the industry could be utilized. Applying these methods lead to reducing gender inequalities, promoting innovation, and advancing education.

5. Statistical analysis

The first thing we had to do in analyzing our data was to prove that there was an actual problem here. This is directly accomplished through analyzing the data collected on professional women in engineering as shown in Table 1, most of the women answered good or excellent on most of the questions. There were only a few questions that stood out as different, however. The questions involving work-life balance and gender equality had more responses of “fair” than any other. The final question on disadvantage/advantage based on gender had an overwhelming amount of negative responses with 40% responses claiming they felt disadvantaged or very disadvantaged and 50% more feeling they had no advantage. There was only one question that was predominately positive responses and that was the question relating to satisfaction with the job. One subject surveyed answered with negative responses on every question.

Table 1 Survey results of female professionals

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Excellent	50%	50%	40%	20%	20%	50%	65%	50%	25%	10%
Good	45%	45%	40%	45%	50%	35%	15%	35%	55%	15%
Fair	0%	0%	15%	30%	20%	15%	15%	10%	15%	45%
Poor	0%	0%	5%	0%	5%	0%	5%	0%	5%	25%
Very Poor	5%	5%	0%	5%	5%	0%	0%	5%	0%	5%

Table 2 Survey results of male professionals

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Excellent	24.24%	21.21%	12.12%	15.15%	18.18%	21.21%	45.46%	24.24%	21.21%	24.24%
Good	57.58%	57.58%	51.52%	51.52%	36.36%	45.46%	45.46%	54.55%	48.4855	30.30%
Fair	6.06%	21.21%	24.24%	24.24%	27.27%	18.18%	6.06%	15.15%	15.15%	42.42%
Poor	12.12%	0%	9%	9.091	9.09%	9.09%	3.03%	3.03%	6.01%	0%
Very Poor	0%	0%	3%	5.00%	9.09%	3.03%	0%	3.03%	9.09%	3.03%

Table 3 Survey results of female students

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Excellent	32.00%	21.00%	19.00%	10.00%	11.00%	28.00%	47.00%	16.00%	13.00%	7.00%
Good	52.00%	52.00%	50.00%	48.00%	34.00%	49.00%	37.00%	31.00%	45.00%	23.00%
Fair	11.00%	23.00%	23.00%	28.00%	29.00%	13.00%	12.00%	33.00%	23.00%	38.00%
Poor	5.00%	4%	8%	12	18.00%	9.00%	4.00%	18.00%	18.00%	25%
Very Poor	0%	0%	0%	1.00%	8.00%	1.00%	0%	2.00%	1.00%	7.00%

Table 4 Survey results of male students

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Excellent	32.00%	21.00%	19.00%	10.00%	11.00%	28.00%	47.00%	16.00%	13.00%	7.00%
Good	52.00%	52.00%	50.00%	48.00%	34.00%	49.00%	37.00%	31.00%	45.00%	23.00%
Fair	11.00%	23.00%	23.00%	28.00%	29.00%	13.00%	12.00%	33.00%	23.00%	38.00%
Poor	5.00%	4.00%	8.00%	12.00%	18.00%	9.00%	4.00%	18.00%	18.00%	25.00%
Very Poor	0%	0.00%	0.00%	1.00%	8.00%	1.00%	0.00%	2.00%	1.00%	7.00%

For female students, Table 3 shows a larger majority chose poor or very poor on many of the options. For the question involving gender equality in the classroom, 26% responded with poor or very poor, compared to 10% in the professionals. This similarly occurred in the questions involving vacation time and mentorship, which each had 20% and 19% respectively respond with poor or very poor. Another case of overly negative responses occurred in the question on advantage based on gender where 32% answered that they felt disadvantaged or very disadvantaged with 38% believing they have no advantage. A far greater percentage of female students classified their school-life balance as fair or better than professionals.

These more specific and varying percentages of the students who responded could partially have the sample size to blame. If there was more data collected from the professional female engineers, the data probably would have been more precise. However, we do feel that the amount of data collected was sufficient to make some claims about the research. It is clear that, while businesses are making an effort to promote gender equality in the workplace, the workplace needs some new reform. Likewise, the classroom environment stands to improve in areas of equality. Some of the data could be explained as situational as well. Students don't necessarily get vacation time, whereas professionals do, which may have been the cause for the skew in the data.

After analyzing the data of male professionals, which is shown in Table 2, we were able to uncover some trends in the data. The professional males answered poor or very poor slightly more than their female counterparts. There were some questions where the data had slightly significant leans toward positive or negative responses. For the question involving gender equality in the workplace, about 18% of the responses indicated that they felt the gender equality was poor or very poor, more than for any other question. Another question that received about 15% poor or very poor responses was the question involving their satisfaction with mentorship. However, there were some extremely positive responses as well. Almost 90% of responders believed they had a good or excellent chance of being promoted. The question on advantage or disadvantage based on gender had almost 97% of responses that were fair or better.

Male students had responses similar to female students as shown in Table 4. Around 16% believed that they had poor or very poor work-life balances compared to 13% in female students. However, there were also some very vast differences found among the data. About 13% of male students believed there was poor or very poor gender equality in the classroom compared to the 26% of female students that

felt there was a problem. Some of the more negative responses by male students involved their likelihood to retire in the profession and satisfaction with vacation time with about 14% on each question. For the responses on the question involving advantage or disadvantage based on gender, most of the people responded with no advantage or better with only about 12% claiming they felt a disadvantage or very disadvantaged in their classrooms.

The sample size for the male responders also slightly hurt the results. The sample size for male professionals wasn't very large (34 submissions) but it was more than the female professionals and we believe supplies an adequate amount to make some inferences. The male students had close to 100 responses so the percentages for their responses are more specific. Something that can be seen from the data is that while both parties responded with mostly positive responses for the questions involving gender equality and their advantages based on gender, the students responded with negative responses more than professionals. This could either show that professionals have a higher awareness of gender differences because of years of experiences or that the students are aware of a less gender equal status in the classroom.

To compare the four different sample groups we looked at the last question that related to advantage and disadvantage from their gender. This question was seen as one of the most valuable for data that would back up our initial thoughts as it related to the question at hand directly. Figures 1 through 4 illustrates the perception of each of the sample group regarding the role of gender in the workplace. As expected, the female participants felt more disadvantaged than the male participants. In each sample, the response with the highest percentage was consistently no advantage. Professional males felt they had the highest advantage with about 54% claiming this but the student males surprisingly stayed mostly in the no advantage range with only 23% believing they had an advantage.

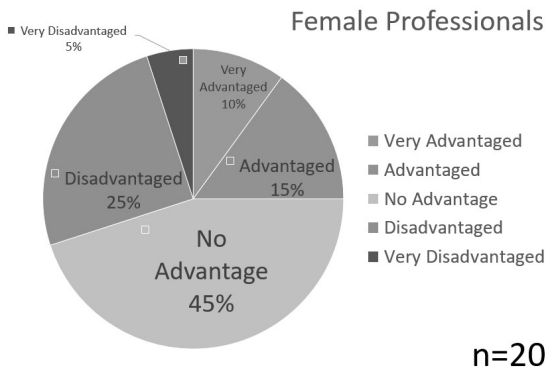

Figure 1. Responses of female professionals

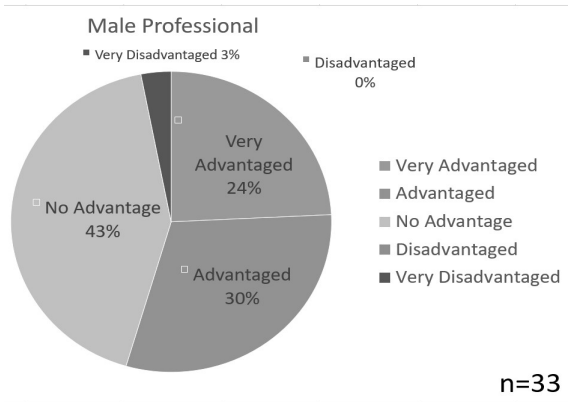

Figure 2. Responses of male professionals

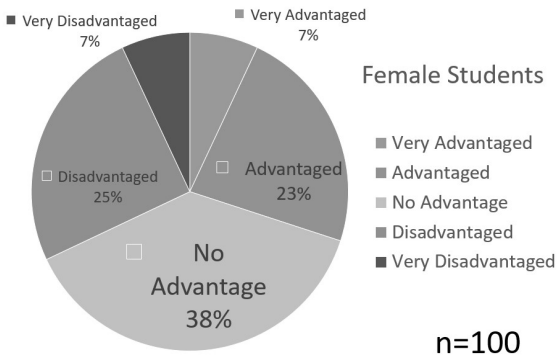

Figure 3. Responses of female students

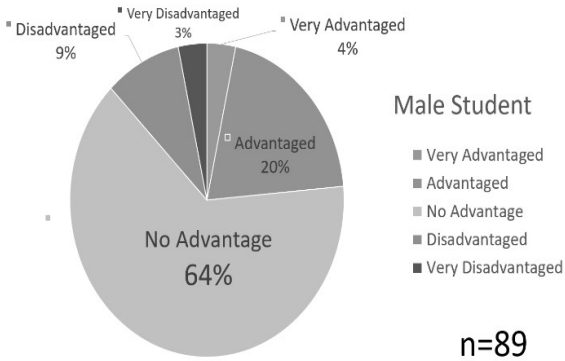

Figure 4. Responses of male students

6. Discussion/Conclusion

There are some very important takeaways from the data we collected. Probably the most significant are that there is definitely a problem when it comes to gender equality in the workplace and classroom. About 30% of the women that were surveyed felt that they faced a disadvantage in their career based purely off of their gender. Meanwhile, a significantly smaller amount of men felt this way. If 30% of women are feeling hardships based on their gender, then changes need to be set in place to better accommodate them.

One of the main goals of this research was to find ways in which the UN's Sustainable Development Goals [SDG's] weren't being met due to the challenges facing women in the engineering profession. We believe that if this research were to be taken into consideration, the employers and professors could find alternate ways to increase the gender equality. In turn, if women felt more comfortable in the workplace and the classroom, some of the SDG's would be easier to attain. These SDG's involved gender equalities, reduced inequalities, quality education, and better work and economic growth.

The surveys that we conducted adequately answered our initial questions on the topic. It's very clear now that there is a problem with gender equality in engineering. The only thing that we weren't able to discover in this research is ways to reduce this inequality. Some further research could be conducted to find solutions to this problem and which solutions are most effective. Case by case studies could be planned and performed where key components of gender equality within the workplace are identified and metrics are made to quantify the progress of specific workplaces. Furthermore, action plans can be made to create a more diverse, open, gender equal workplace or classroom. If this the current system of the masculine workplace allows being dominant, our society likely won't be able to achieve all of the SDG's set for 2030 and our civilization will be worse off because of it.

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Evaluation of Safety Subcultures within a Privately Owned Heavy Equipment Dealership

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Abstract

The importance of safety in the heavy equipment dealership industry cannot be disputed. Furthermore, safety culture and the emergence of safety subcultures can compromise an entire safety program. A need exists to determine if safety subcultures are present between store locations and it is also critical to understand if a significant difference exists between the safety culture of existing stores and those that have been recently acquired. In this study, the authors assessed the differences in safety culture between heavy equipment dealership locations and between newly acquired units. It was determined that the between store variation of median Surveys Per Associate (SPA) scores are statistically different while the variation of median SPA scores between the newly acquired and existing facilities are not statistically different.

Recommendations for future research include investigation of the leadership practices between the stores to determine best practices that lead to improved safety and safety culture. Likewise, initiate an inquiry into the process of store acquisition and emergence of safety culture; what factors influenced success and lead to the creation of a positive safety culture.

1. Introduction to Safety Subculture

This study focuses on a heavy equipment dealership that sells and services mining and construction equipment. One critical factor that impacts this company and most others is occupational safety and how well companies perform in keeping their associates safe on the job. Being a heavy equipment dealer, occupational safety is a critical factor since the nature of the business presents many safety risk factors that most organizations do not encounter. The machines being repaired are very heavy requiring large cranes and/or hydraulic presses for lifting and other power tools in the repair process. Use of these tools and equipment can interject unusual risk factors. Having a consistent safety culture across the dealership coupled with training on how the technicians handle these risk factors is critical to safety. This study is significant because it attempts to identify if the safety culture is consistent throughout a multi-location service organization or have safety sub-cultures emerged which can be a barrier to safety related performance measures.

In order to assess safety sub culture, a description of subculture must be provided to lay the framework for this study. Edgar Schien [1], a recognized expert in the study of organization culture states that any group who has a shared interest and who has gone through learning together will have it's own subculture. Thus, subculture will often exist within an overall organizational culture. Reiman and Rollenhagen (2013) assert “The general notion of subculture is vague because it is not always clear on what grounds a subculture is defined. (p. 6)” These researchers expand on the notion of vague subculture by noting it can be defined from various perspectives such as: (a) groups position within the organization, (b) age (i.e. millennial or boomer culture), or as aligned with this study, (c) a specific focus area which would

encompass safety subculture in the heavy equipment industry, and specifically, the emerging subculture of those responsible for safety within the respective facilities making up this study. While published definitions exist for safety subculture, Antonsen (2009) offers the following, "if one is to use the term safety culture it should be only as a conceptual label, referring to the dynamic and complex relationship between culture and safety". Based on the concept of safety culture offered by Antonsen, [3] and the establishment of safety culture within the focus organization, subculture will be assed by comparing the performance of the safety policy or SPA (safety recognition survey per associate) among various facility locations. The literature review that follows presents the relationship between culture, subculture and the importance of performance in organizational safety initiatives.

2. Study Background & Literature Review

2.1. Study Background

This company in this study is composed of twenty-one store locations across three states and has made great strides in elevating the safety culture over the last two years. As previously mentioned, the heavy equipment business can be full of unique risk factors. The new safety culture in this organization focuses on everyone being mindful of his or her coworkers and to always be looking for risk factors that go unnoticed or unreported. Once a risk is found it is imperative to promptly say something about it and document the risk. The organization experienced a strategic change in 2015 by acquiring three smaller yet similar dealerships. Lighter markers on Figure 1 represent the stores with new team members from the acquisitions.

Figure 1. Store Locations

Five of these store locations are shared stores meaning they are large multidivisional stores with separate management for each division and are shown by the darker markers. Multidivisional means there are different types of equipment sold at these stores ranging from construction equipment, forestry equipment, electric power and lift trucks. The store management is structured by these divisional and business functional boundaries. Existing single divisional stores with no acquisition impact are noted with green markers.

The Executive Management of this company holds no other critical success factor higher than safety as this deals with our associate's livelihood on a daily basis. There is an expectation set by the corporate office that defines the safety culture and how each store location should operate. The authors hypothesize

that there are subcultural differences between the store locations and that these stores may not be meeting the required safety engagement and fail to uphold the culture. Some store may perform better than others, thus it is the authors belief that this could be due to the emergence of safety subcultures. The safety strategy is comprised of many standalone but strategically related initiatives designed to grow the desired safety culture and to engage the associates to be involved in his or her own and their coworker's safety.

One such initiative in the multidisciplinary strategy is the safety recognition program. This safety recognition program is the basis for evaluation of safety subculture. If an employee observes a safe or unsafe act or a safety risk (near miss) while executing their daily job duties, the employee can (highly encouraged by policy) immediately create a 5 question appraisal. This appraisal can recognize the safe act or provide constructive feedback for an observed unsafe act. An example of this appraisal is shown in Figure 2.

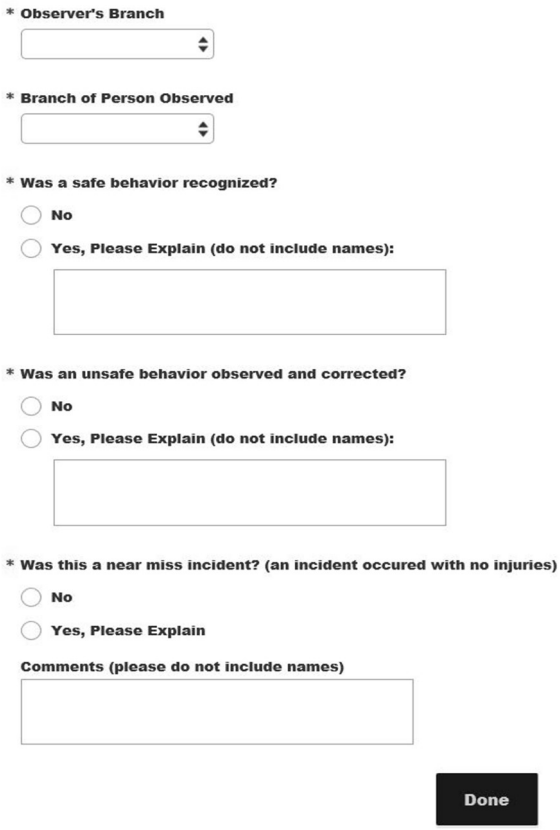


Figure 2. Safety Recognition Survey

This program is designed to engage the associate in proactive safety practices and to teach associates to recognize safe and unsafe actions in both their work and their coworkers. Periodic and incident specific training is provided for associates to help identify these risks factors and how to effectively observe repair processes from a safety first perspective. The repetition of entering these surveys should help embed the observance of, and recognition of, safe work actions into their daily work. Such a survey initiative is designed to be a positive cultural change tool to keep safety constantly in the minds of our associates.

2.2. Literature Review

According to Lievens & Vlerick (2013) safety performance can be defined as the behaviors that employees exhibit to promote and adhere to safety in the workplace. A safety culture, as presented by

Chera, Mazur, Adams, Kim, Milosky & Marks (2016), is a safety mindfulness that envelopes an organization from a systems based perspective. Researchers Lok & Crawford, (2016) state that if the vision of corporate organizational culture is not communicated clearly enough, the subculture may take precedence over the organizational culture allowing the subculture to be dominant. Spigener (2016) claims "safety-related decisions require leaders to make accurate judgments about future likelihoods and leaders must pull safety into all of the thought processes in a consistent way". Mullen, Kelloway, & Teed (2011) found that different safety leadership styles can greatly impact a work force and impact workgroups within the organization differently Clarke (2012) believes that Transformational leadership has a positive association with both perceived safety climate and safety participation of the associates in the organization creating differences in the work group depending on the group leader. Subcultures and commitment are strongly correlated. As stated by Lok, Westwood and Crawford (2005), it is critical to analyze commitment at the subcultural level when exploring member's attitudes and behavior. It is shown that subculture commitment is often times stronger than the desired corporate culture. Knowing this, there should be a correlation between safety engagement and the actions spoken of by Lok et. al. (2005), could be the participation rate in the safety initiatives. The more committed the store is in the safety culture the more surveys per capita at each store should generate thus "perceived organizational subcultures have a significant relationship to commitment" (Lok, et. al., 2005). "The official culture is established in large part by top management. The concept of an organizational subculture refers to shared understandings about the organization's mission and standards of conduct, as well as the corresponding organized practices that emerge in a group of employees" (Mullen, 2011).

3. Problem Statement, Study Method and Hypothesis

3.1. Problem Statement

Safety is the one of the most important aspects of operating a heavy equipment dealership. Furthermore, the emergence of safety subcultures can compromise an entire safety program. Therefore, a need exists to determine if safety subcultures are present between store locations. Additionally, it is critical to understand if a significant difference exists between the safety culture of existing stores and those that have been recently acquired. Both have implications to the safety culture and are of significant importance to management.

When talking about safety and quality subcultures it is imperative to understand the meaning and ramifications of having multiple cultures of safety within the corporate expectation of what safety should be. This variation could be disastrous if a particular subculture strays too far from the organizational expectation. Even though there is a stated corporate culture there can be groups of associates that create their own practices (often with good intent) that can deviate from standard creating a subculture different from the corporate expectations. It is the management's responsibility to communicate clearly the corporate expectation of what the corporate safety culture should be so that this subculture does not occur. Such subcultures could bypass procedures placing associates lives at risk in the potentially dangerous situations technicians work within. Commitment by all associates is critical to the success of the safety initiatives and the sustainability of the safety culture.

3.2. Study Method

The methods used to determine the cultural commitment requires the assembly of all recognition survey data for the first 28 weeks of 2016 by store location. Each store had to report a weekly survey count total of surveys entered into the organizations ERP system. It should be noted that the stores are of different sizes, employ different number of associates and have different store leadership. To normalize these differences, the total number of associates in that store is divided into the number of surveys to

produce a number of surveys per associate (SPA) which is the response variable to asses differences in subculture between store locations.

Additionally, the company in this study recently completed an acquisition of 3 similar yet smaller companies. It was questioned by some on the management team that the acquired companies did not have nearly the same focus on safety as the original stores did. To understand and validate this question/assertion another variable was added to see how the SPA between the original store populations compared to the population of the newly acquired stores. Is the safety culture of the original stores different from the population of stores that were recently purchased? To compare these two populations a Mood Median Test was used to determine if there are differences in the median survey per associate (SPA) using the SPA as the response variable.

3.3. Hypothesis

There are two separate hypotheses to test in this study:

- Hypothesis 1 tests the variation between the stores to determine if the medians are statistically different. The SPA will be the continuous response variable.

  Ho: Median SPA $_{\text{store 1}}$ = median SPA $_{\text{store 2}}$ = median SPA $_{\text{store ...}}$ = median SPA $_{\text{store 19}}$

  Ha: At least one store median $\neq$ to the median of the other stores.
- Hypothesis 2 tests the difference between recently acquired stores and existing stores.

  Ho: Median SPA original store = median SPA new store.

  Ha: Median SPA original store $\neq$ median SPA new store.

4. Study Limitations

There are some limitations to this research. Some of the stores exhibited low n-values that reduce the estimation and accuracy of confidence intervals, however this does convey a lack of commitment within the store's safety culture. The data does not differentiate the between divisional differences in leadership in the shared stores mentioned in the introduction. These divisional differences may interject some noise in the analysis and offers another contributing factor in the assessment of safety subculture.

5. Data Analysis and Discussion of Results

The initial step in the analysis was to validate that the data was distributed normally. Using the normality plot and Anderson-Darling test as an evaluator of normality, the SPA data appears to be non-normal. See Figure 3. Therefore, non-parametric statistics must be used in the analysis.

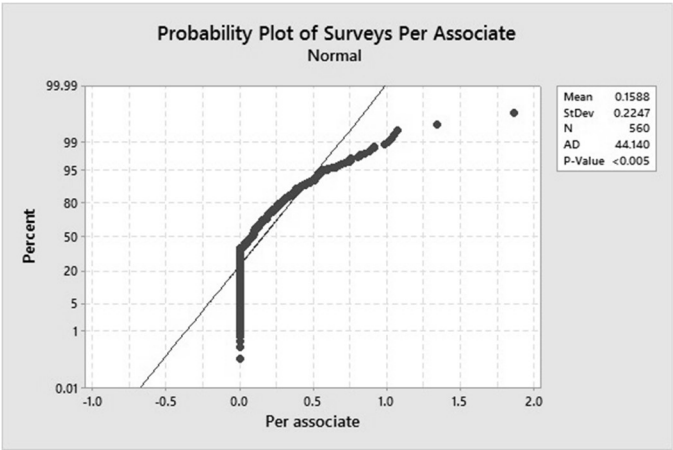


Figure 3. Test for Normality

A sample of the data set showing the 28 weeks of data for one store location is noted in Table 1. The column headings across the top line represent the store location, the week number for the 28-week study, total number of surveys completed that week, the store status (i.e. original or newly acquired), number of employees at the store. To normalize the data and to account for store size, there was a derived field named surveys per associate that will allow for an equal comparison of survey totals by store.

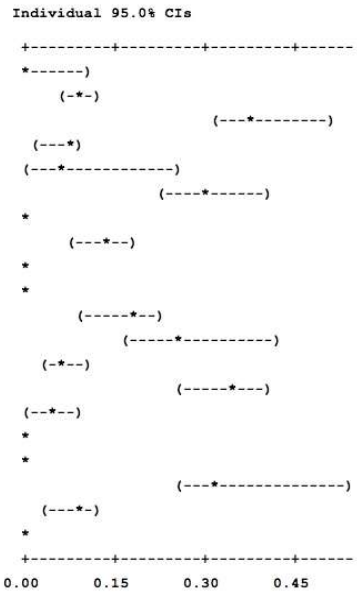
Table 1. Date Set Example – One Store

Store	Week	Total	Old (O) New (N)	Employee	SPA
Chesapeake	1	3	N	42	0.071
Chesapeake	2	7	N	42	0.167
Chesapeake	3	10	N	42	0.238
Chesapeake	4	11	N	42	0.262
Chesapeake	5	15	N	42	0.357
Chesapeake	6	10	N	42	0.238
Chesapeake	7	8	N	42	0.190
Chesapeake	8	12	N	42	0.286
Chesapeake	9	31	N	42	0.738
Chesapeake	10	34	N	42	0.810
Chesapeake	11	43	N	42	1.024
Chesapeake	12	19	N	42	0.452
Chesapeake	13	28	N	42	0.667
Chesapeake	14	17	N	42	0.405
Chesapeake	15	23	N	42	0.548

The data from the first analysis that tests hypothesis #1 (comparing the SPA by store location) is shown in Table 2. One can see the Mood Median Test p-value is 0.000 with an alpha value of 0.05. Thus, one rejects the null hypothesis that the medians are different between the stores inferring that there is a difference between the store SPA values.

Table 2. Moods Median Test – SPA by Store Location

Store	N≤	N>	Median	Q3-Q1
Beaufort	18	10	0.000	0.100
Charleston	14	14	0.087	0.094
Chesapeake	1	27	0.369	0.393
Discovery	14	14	0.071	0.095
Elizabethtown	14	14	0.063	0.250
Fayetteville	2	26	0.300	0.265
Florence	28	0	0.000	0.000
Garner	9	19	0.129	0.129
Greenville For	25	3	0.000	0.000
Greenville Lift	23	5	0.000	0.036
Harrisonburg	7	21	0.182	0.250
Mebane	4	24	0.250	0.406
Raleigh	18	10	0.060	0.090
Richmond	1	27	0.344	0.234
Roanoake	22	6	0.042	0.083
Rocky Mt	26	2	0.000	0.000
Wanchese	26	2	0.000	0.000
Washington	2	26	0.322	0.328
Wilmington	11	17	0.088	0.118
Winchester	22	6	0.000	0.000



Chi-Square = 236.23 DF = 19 P = 0.000

Overall median = 0.083

Testing hypothesis #2, (comparing the two groups of original and new store populations) the results of the Mood Median Test are shown in Table 3. The resulting p-value is 0.214 and alpha is 0.05. Thus, based on the p-value one fail to reject the null implying there is not difference between original and newly acquired stores. This indicates there is no significant variation in the safety cultures based on the SPA values.

Table 3. Mood Median Test SPA for New Acquired Stores vs Currently Owned Stores

O/N	N≤	N>	Median	Q3-Q1
N	122	102	0.0500	0.2500
O	165	171	0.0882	0.2249

```
                                  Individual 95.0% CIs
                                  +---------+---------+---------+------
                                  (----------------*--------------)
                                                       (-----*---)
                                  +---------+---------+---------+------
                                0.000     0.030     0.060     0.090
```

O = Old, previous stores

N = Newly acquired stores

Chi-Square = 1.54 DF = 1 P = 0.214

Overall median = 0.0833

A 95.0% CI for median(N) - median(O): (-0.0952,0.0076)

There are stores that are considerably different in the participation rates of the safety recognition surveys. Figure 4 presents a box plot indicating significant differences between the store locations.

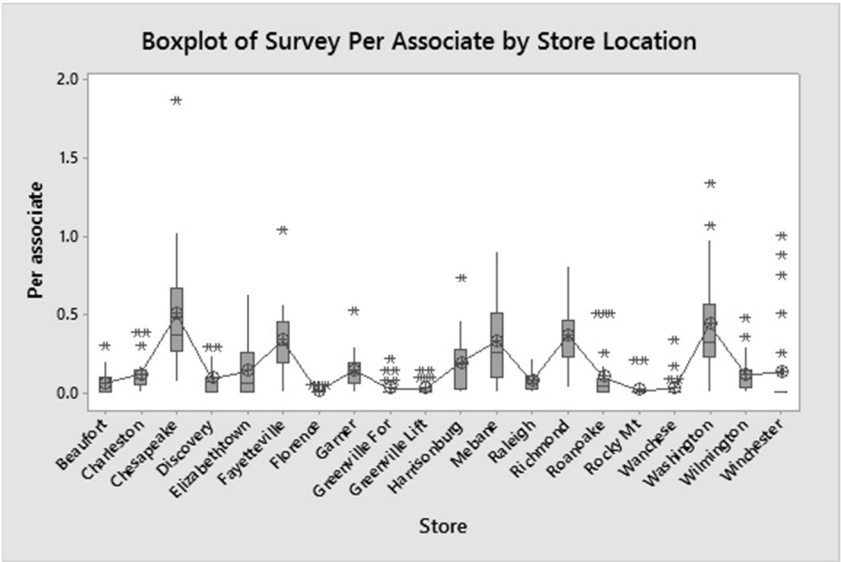


Figure 4. Boxplot SPA by Store Location

5.1. Discussion of Results

The between new and old store population results are quite unexpected. These researchers felt the new stores recently acquired 8 months prior would not be as engaged in the safety culture as the original stores. Based on the data, the engagement factor between a new location and an original store indicates no real difference in the level of SPA engagement. Could this be because the new stores are more engaged in following the new policies of their new company or is it simply the management team from the purchasing company did a extraordinary job during the acquisition in onboarding process explaining the

safety culture. Figure 5 presents depicts the similarities between the original and newly acquired stores.

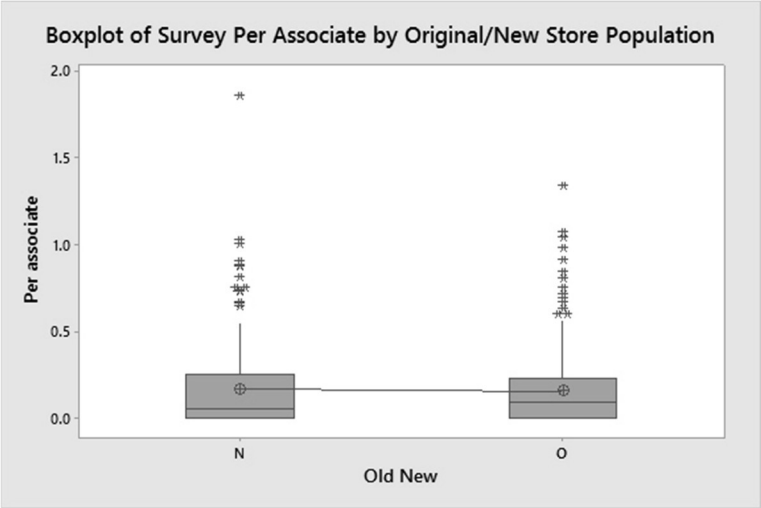


Figure 5. Boxplot SPA by Store Location

This may offer another area of study to determine how and why there is no safety subculture between these two unique populations.

6. Conclusions & Future Considerations

From part one of the study it can be concluded that there is a strong probability safety subcultures are present within this company based on the SPA (survey per associate). Looking at the between store variation there is quite a difference in the participation rates. This could be due to the store level leadership or to the size of the store thus making a big difference in the engagement. To further explore the difference in subculture, it would be advantageous to study the high performing stores to identify what they are doing right and also to identify why the low performing stores are performing inadequately. This deeper dive into safety culture differences could land the researcher on what exactly needs to occur to improve the safety culture engagement and thus the quality and safety culture for everyone. Another area of further study would be the different divisional leaders at the shared store level and leadership engagement. It would be interesting to determine how this impacted the engagement in safety culture between the divisions at these locations. It would be interesting to measure the participation rates in other safety initiatives that are running concurrently to see if the results could be replicated and would therefore reinforce the correlation and causation question.

Part two of this study shows there to be no significant differences between the two populations of original store and newly acquired store SPA's. This result is unexpected yet refreshing knowing that the corporate culture has permeated these stores so quickly. This could be further explored by gathering feedback from the new store groups on what could have been done better to assist them in the transition with regards to safety training.

Use of this method to assess the existence of safety subcultures could develop into an instrument to determine if safety related policy, programs and/or procedures are effective. Using this study as the baseline, one could periodically use this same technique to determine progress or decline of any safety subculture. Additionally, if new safety related practices or policies are implemented, a follow up assessment, using the SPA technique in this study, could serve as method to measure the effectiveness of any recent safety related initiative. In effect, the use of SPA method becomes the safety subculture assessment instrument. The instrument may be used by other organizations in a similar fashion.

The identification of risk factors in potentially dangerous work is critical in the safety and well-being of the workforce. This identification of risk factors needs to be addressed in a very consistent manner and corporate culture should enable this consistency. Deviation from this consistency and the evolution of safety subcultures can be detrimental to the safety of the workers and could elevate a risk factor into an accident. When safety subcultures are found, forthright efforts should be employed to evaluate why there are deviations from the norm and either learn positive knowledge and correct the corporate strategy or correct the harmful variation that could lead to accidents.

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Antecedents of voluntary turnover among U.S. offshore commercial mariners: Satisfaction and perceived organizational support

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Abstract

Many jobs have inherent satisfaction challenges (e.g., repetitive tasks, social isolation, lack of autonomy, etc.). Yet employees in these positions are often highly skilled and difficult to replace. In such circumstances, minimizing employee turnover becomes a key strategic factor. However, research suggests that low satisfaction is likely to have a strong, negative effect on turnover. In this paper, we explore how managers might create an environment where valuable employees are willing to stay in positions with inherent satisfaction challenges. We propose that in positions with satisfaction challenges that are integral to the work itself, the degree to which mangers provide employees with a sense of perceived organizational support will become more important relative to satisfaction in explaining employee turnover rates. We test our proposals using a sample of survey data gathered from U.S. commercial offshore mariners who left seafaring positions in favor of shore-based jobs. Results of our analysis provide partial support for our proposals and open some interesting doors for future research.

1. Introduction

Satisfaction is an important factor contributing to employee turnover rates. Many scholars have shown a significant inverse relationship between employee satisfaction and turnover (*e.g.,* Griffeth, Hom & Gaertner, 2000; Lambert, Hogan & Barton, 2001; Lum *et al.,* 1998; Shore & Martin, 1989; Tett & Meyer, 1993). However, some positions have inherent barriers to employee satisfaction. The aim of this research is to explore what factors drive voluntary employee turnover when there are significant satisfaction challenges that are integral to the work itself. We propose that, in the absence of optimal satisfaction, employees may become more sensitive to the level of perceived organizational support (POS) and that this sensitivity will be reflected in the turnover rate.

To test our ideas, we explore survey data from a sample of U.S. mariners who have worked in commercial seafaring positions that required long-term travel at sea (we refer to these people as offshore commercial mariners), but left that position in favor of a shore-based job. We focus our analysis on the shipping industry. Yet similar inherent employee satisfaction challenges may be found in many fields, including; military service, trucking, aviation, scientific field research, construction, and cross-border business management or sales, among others.

2. Perceived organizational support and satisfaction as turnover antecedents

In addition to employee satisfaction, a key variable that stands out in the management literature as an important antecedent of employee turnover is perceived organizational support (*e.g.,* Allen, Shore & Griffeth, 2003; Dawley, Houghton & Bucklew, 2010; Maertz, *et al*., 2007). With regard to organizational commitment, the desire to stay is motivated largely by a sense of perceived organizational support (POS) (Allen, Shore & Griffeth, 2003; Eisenberger, Stinglhamber & Vandenberghie, 2002). POS describes an

employee's beliefs about the degree to which the organization they work for appreciates the employee's contribution and cares enough to support their general welfare (Eisenberger, Stinglhamber & Vandenberghie, 2002). Employers can support an employee's sense of POS by giving heartfelt praise or offering rewards that are not contractually or normatively required. Employers may also reduce an employee's workload or provide increased time off following a significant loss or during a stressful period. Access to employer-sponsored training opportunities or overlooking deficiencies when awarding promotions may also contribute to an employee's sense of POS.

We propose that in jobs with inherent satisfaction challenges, employees may become especially sensitive to the level of perceived organizational support (POS) that their managers, sometimes working in more comfortable or engaging surroundings, are able to provide. We predict that this sensitivity may be reflected in the likelihood of employees to leave. After all, efforts at cultivating POS are, by definition, designed to create a sense in employees that their managers really care about their wellbeing (Moorman, Blakely & Niehoff, 1998). Commitment to the organization and its goals is how employees provide reciprocation for the support that employers offer (Eisenberger, *et al.,* 2001; Moorman, Blakely & Niehoff, 1998).

3. Voluntary turnover in the U.S. maritime industry

Several important determinates of seafarer turnover are repeatedly identified in research on the topic. An issue that consistently comes up as one of the most difficult aspects of life at sea is social isolation. Sixty-two percent of respondents to the 2012 Shiptalk Life at Sea Survey[1] said that separation from family and friends on shore was one of the most challenging parts of a seafaring career. This finding is mirrored in other research on turnover in the maritime industry (*e.g.,* Ceasar, Cahoon & Fei, 2015; Kantharia, 2017). Other potential satisfaction issues frequently identified in maritime industry research include: safety concerns, risk of criminal prosecution, long hours, repetitive/regimented tasks, poor amenities (food, living quarters, etc.).

Partly due to high rates of unionization among U.S. mariners, there is not a cultural norm of high organizational commitment. Seafarers tend to move between shipping firms at a relatively high rate (Fei, Chen & Chen, 2009). Moreover, there tends to be relatively low occupational commitment, or desire to remain in one's current occupation regardless of the specific employer. Qualified mariners are often lured away from seafaring positions by offers from employers who would like to exploit their unique skills and knowledge of the industry in shore side positions (Caesar, Cahoon & Fei, 2013; Fei, Chen & Chen, 2009). Indeed, movement into shore side positions is a primary driver of the shortage of seafarers and this trend appears to be on the rise in recent years (Caesar, Cahoon & Fei, 2015).

4. Method

To conduct our survey, we contacted 1,110 cadets who graduated with degrees in marine engineering technology or maritime transportation from the California State University Maritime Academy between the years 1995-2015. We required respondents to our survey to meet the following criteria:

- Worked for a commercial shipping operation in a position that required travel away from home that consumes the majority of the year where each trip lasts for more than a week.
- Worked aboard a U.S. flagged vessel for the span of at least a year.

[1] The Life At Sea survey is an international assessment completed by registered user of Shiptalk recruitment about their attitudes relating to the maritime industry. With 488 respondents, it is one of the most comprehensive surveys in the field. There is a disproportionate representation (40%) of respondents from English-speaking countries.

- Decided to leave a position that required long-term travel at sea for one that does not.

We received 59 responses to our survey. A 5-point Likert scale was used to determine respondents' level of agreement with a range of statements that, based on our research, we thought may contribute to their decision to leave a position that required long-term travel at sea. 1 indicated strongly agree, 2 agree, 3 disagree, 4 strongly disagree, and 5 undecided.

When exploring the antecedents of employee turnover, rather than measuring actual numbers of people who leave the organization, scholars often operationalize turnover as employees' self-reported quit intentions (*e.g.,* DeConinck & Stilwell, 2004; Lum *et al.,* 1998; Singh & Loncar, 2010; Vandenberghe & Tremblay, 2008). One reason that scholars frequently prefer quit intentions to actual turnover is that it can be difficult to gather data about people who have actually left the organization. Despite the research advantages of using self-reported quit intentions, there are significant weaknesses. Self-reported quit intention is the best known predictor of real employee turnover, yet the two variables only have a correlation of 0.38 (Griffeth, Hom & Gaertner, 2000). Due to these weaknesses of self-reported quit intentions, some scholars prefer to use the variable tenure (*e.g.,* Bedeian & Ferris, 1992; Motowidlo, 1983).

When management researchers explore employee turnover, they often focus on the firm level. However, it generally is not reasonable in the U.S. maritime industry to conceive of turnover as an organizational level construct. U.S. commercial mariners tend to move easily between shipping firms based on what union postings become available. Hence, we operationalize turnover as the number of consecutive year's respondents worked as an offshore commercial mariner. We call our dependent variable occupational tenure.

Five facets are thought to most strongly impact overall job satisfaction; pay, promotion, supervision, coworker relationships, and the duties associated with the work itself (Ironson *et al.,* 1989; Russell *et al.,* 2004). Because of the strong link between job satisfaction and turnover, we asked respondents about their feelings relating to these five facets of job satisfaction.

We likewise sought to determine whether factors relating to POS may have influenced offshore mariners' decisions to leave. In particular, we inquired about former offshore mariners' feelings about the adequacy of company efforts to keep mariners in contact with loved ones, access to training opportunities, safety precautions, rest opportunities, and shipboard amenities.

One of the advantages of targeting people who have left positions as offshore mariners was our ability to inquire about pull factors (positions they took after leaving) and their feelings about their time at sea in retrospect. Hence, we asked respondents if they experienced a growth in income after leaving and whether their post-seafaring position presented significant opportunities for income growth.

We also asked mariners to think back to when they began their careers as commercial mariners and to estimate how long they projected they would remain in this career when they started. Because of the importance of self-reported quit intentions in describing employee turnover (Griffeth, Hom & Gaertner, 2000), we included the control variable expected tenure. After exploring the data, we decided to introduce a second dependent variable called follow-through, which we calculated as the actual occupational tenure divided by the occupational tenure that the mariner projected at the start of their career.

We used a structural equation model to explore the data. We also ran Cronbach's Alpha tests on the five satisfaction variables and on the four POS variables. Finding a score of 0.776 on the four POS variables, we felt comfortable loading them onto a single construct in our model.

5. Results

The average actual occupational tenure for our sample was 6.7 years. However, when they started their careers as mariners, respondents expected to remain at sea for an average of 12.8 years. Pay did

not appear to be a strong motivator to leave. Twenty-five percent of our respondents disagreed and 47% strongly agreed that pay was higher in the position they moved into after leaving a position as an offshore commercial mariner. In our initial model with occupational tenure as the dependent variable, pay did not have a significant effect. However, none of our other independent variables had a significant effect either, except for expected tenure.

Table 1: Dependent Variable - Occupational Tenure

Independent Variable	Coefficient	T-Ratio
Satisfaction with Pay	-0.060	0.425
Satisfaction with Benefits	0.108	0.514
Satisfaction with Supervisor	0.077	0.345
Satisfaction with Coworkers	-0.089	0.597
Satisfaction with Work	-0.124	1.038
Satisfaction with Promotion Opportunities	0.115	1.156
Perceived Organizational Support	0.260	1.583
Expected Tenure	0.405	2.636*

Noticing the importance of expected tenure in explaining turnover rates, we sought to understand this relationship better. Hence, we divided up our sample into two groups; those who expected to stay for a long time when they started their careers as offshore mariners (> or = 10 years) and those who expected to stay for a short time (< 10 years). Table 2 shows that mariners who planned to stay for longer periods of time when they started their careers had much less follow-through than mariners who expected to stay for shorter periods of time (*i.e.,* they stayed for a lower proportion of the time they planned to when they started their careers). So the difference between expected tenure and actual tenure is being driven almost totally by one group of respondents; those who expected to stay in the industry for a long period of time.

Table 2: Occupational Tenure - Expected vs. Actual

	N Respondents	Avg. Expected Yrs	Avg. Actual Yrs
Expected to Stay > or = 10yrs	38	17	7.8
Expected to stay <10yrs	21	4.4	4.2

We sought to understand whether POS might help explain the difference in follow-through between mariners who expected to stay for longer vs. shorter periods of time when they began their careers. So we ran a second structural equation model that was the same as the first, except with follow-through as the dependent variable and expected tenure omitted as an independent variable.

Table 3: Dependent Variable – Follow-through		
Independent Variable	**Coefficient**	**T-Ratio**
Satisfaction with Pay	0.032	0.196
Satisfaction with Benefits	0.113	0.576
Satisfaction with Supervisor	0.025	0.117
Satisfaction with Coworkers	-0.234	1.341
Satisfaction with Work	-0.339	1.654
Satisfaction with Promotion Opportunities	-0.095	0.696
Perceived Organizational Support	0.426	2.952*

In this model, there was a strong, inverse relationship between POS and follow-through such that employees who reported higher levels of POS gave a higher percentage of follow-through (stayed closer to the amount of time they projected when they started their career).

6. Discussion and conclusion

Our results point to three important takeaways. First, our findings confirm prior research that indicates that self-reported quit intentions are the strongest predictor of actual turnover (e.g., Griffeth, Hom & Gaertner, 2000). Second, our research suggests that turnover in the maritime industry is being driven mainly by employees who began their careers with high levels of long-term commitment and then lost some of that enthusiasm a few years after beginning their careers. Third, our results support the idea that the effect of POS on turnover may be difficult to fully appreciate using traditional measures of turnover because the effects may be concentrated among the most enthusiastic or long-term oriented employees.

Future researchers may expand on this work by exploring the relationship between POS and other measures of employee commitment, like self-reported levels of enthusiasm, or comparing among types of commitment (*e.g.,* affective, continuance, and normative). Future research may also make useful findings by exploring jobs on a continuum of satisfaction to confirm whether POS becomes more relatively important to explaining turnover as average levels of satisfaction decrease.

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Executive Leadership Diversity: AA study of influencing factors

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Abstract

On almost every website of Fortune 500 firms, there is a reference for commitment to diversity within their workforce. One would assume that such companies would have a high level of diversity within their executive leadership. Surprisingly, there appears to be much less than one would expect. The focus of this paper is on the level of diversity within the executive suite and the factors that may influence that diversity.

The analysis contained in this paper provides insight on the relationship between specific CEO socio-demographics/company demographics, and the level of diversity within the Top Management Team (TMT) and Executives of Fortune 500 firms. Data from a random sample of two hundred fifty Fortune 500 companies was collected. Due to the low percentage of Female CEOs represented within the random data, all fifty-five companies led by female CEOs within the Fortune 1000 were added to the sample data resulting in a total of two hundred ninety-one companies analyzed. Data regarding the CEOs and their companies were collected from various reputable websites including Bloomberg, Forbes, along with each company's official website.

An executive leadership level of diversity (New Diversity Index) was calculated for each company contained within the samples and this was used as the Dependent Variable. The definition of the level of executive diversity used for this study is the extent to which an executive leadership team is anything other than a white male. Data regarding nine independent variables was collected for each company to determine if any variable indicated a significant relationship with the level of diversity within the executive leadership. Based on ANOVA and multiple linear regression analysis, six of the original nine independent variables were eliminated due to unacceptable results. However, CEO Gender, CEO Political Affiliation and Company Region all appeared to be significant and may well be related to the New Diversity Index. It was concluded that the level of diversity within a company's executive leadership may well be influenced by the CEO's gender, the location of the company, as well as the CEO's political affiliation. In was then inferred that the highest level of diversity with executive leadership of the top Fortune firms may well occur when the CEO is a female, a democrat, and the company is located in the Western region of the United States.

1. Background

The concept of diversity in executive leadership is a popular topic that continues to be frequently discussed within major organizations and also by their boards. When considering what a diverse leadership team brings to company performance, one first must define diversity. The traditional definition of diversity is fungible and can include sex, age, race, culture, traditions, personality, work experience and beliefs (Alesimo, 2005). In this research paper diversity is defined explicitly by as anyone other than a white male. These criteria within executive leaders can become very important to the direction and performance of the firm, especially if the corporate strategy is global.

The presence of a diverse leadership team may well allow for a variety of thought and creativity. This grants an organization the potential opportunity to move outside of traditional corporate direction and innovate. Innovation has in the past often resulted in positive performance. In addition, a diverse leadership team may well be more likely to hire and develop a diverse employee population; this also can potentially move the company forward by making the firm more strategically innovative and flexible. Since innovation has been shown to drive company performance and profit and result in a competitive advantage in the marketplace, diversity in the leadership team may well be a key for future success in fortune 500 firms. (McCleod and Lobel, 1992). But what are the factors that are driving a diverse executive leadership team?

More organizations are moving their attention to supporting one potential factor- the presence of a female CEO. There may well be a link between how diverse the executive leaders are and whether the CEO is male or female. In this research paper a random sample of Fortune 500 companies is reviewed along with the diversity mix of the executive leaders and the relationship to the gender of the CEO. The result of examining the sample and the multiple variables is intended to shed light on whether or not there is a relationship that exists between CEO gender and executive leadership diversity. Other potential factors are also tested for potential inclusion.

2. Literature Review

There is much speculation and discussion around the need for executive leadership with diverse backgrounds and what impact that has on company performance. The topic of diversity has evolved over the years from firms simply trying to meet governmental and legal requirements into an area of corporate competitiveness and strategy. As early as 1991 Cox and Blake suggested that managers were turning their attention to cultural diversity and that new management research was suggesting that organizations should value diversity as a means to achieve better firm effectiveness (1991, Cox and Blake). In the ensuing years managerial research was ambivalent on the subject. Robinson and Dechant expressed the view that while many companies seem to value diversity, business diversity was not a priority among business alternatives (1997 Robinson and Dechant). In 1998 Miller, Burke and Glick indicated that executive diversity may in fact inhibit the relationship between executive performance and executive diversity (1998, Miller, Burke and Glick). Shortly thereafter, Wright and Snell posited that "the notion of diversity and its consequences extends beyond the obvious issues of race and gender" …. and "that evidence suggests that diversity represents a potential for both constructive and destructive outcomes." (Wright and Snell, 1999). Other research on CEO diversity indicated that when the CEO is a female, the firm risk level is smaller than when the CEO is a male (Khan and Vieito, 2013).

As the 21st century started to unwind, most managerial research began to turn in a more favorable direction. In fact, it was now observable that firms were spending considerable resources on diversity. Diversity was starting to be seen not only as favorable, but also as a best practice i.e. corporations were seen spending huge budgets focused on the area of diversity to include many types of programs designed to attract, retain and develop talent and leadership with diverse backgrounds (Jayne & Dipboye, 2004). "It is estimated that organizations spend $8 billion annually on diversity training." (Jayne & Dipboye, 2004). In 2006 a paper by Seigyoung and Bulent addressed "how TMT (top management teams) experience diversity (and how) TMT functional diversity (aids) in explaining the effect of customer orientation on organizational performance". It (was) argued that when TMT functional diversity is leveraged with TMT experience diversity, this bundled tacit knowledge operates as a transformational capability, strengthening the relationship between customer orientation and organizational performance. (Seigyoung and Bulent, 2006).

Subsequent papers continued to support this notion. "Cultural diversity in the workplace drives profit and increases innovation, which are key factors in gaining a competitive edge in the marketplace"

(Vaughn, 2009). There have been studies performed to show a positive correlation between diversity and revenue, market share and profitability. The idea in this research is that a more diverse executive leadership drives the overall organizational diversity which ultimately impacts the bottom line (Vaughn, 2009). Along these lines female CEO's seem to also impact company performance one must consider the CEO and what leaders they hire for their TMT. There seems to be a relationship between a female CEO and the level of diversity within her executive team. A female CEO seems to have a tendency to support and encourage an expansive realm of diverse backgrounds within her team including a higher percentage of female executives. Several research projects have argued that the presence of executive women leaders encourages a greater percentage of overall female leaders within an organization. This dynamic has proven to result in greater company profitability than those companies without female executives. In one study it was argued that the difference translated to the tune of approximately 6 percentage points. (D'Onofrio, 2016)

3. Hypothesis

Null Hypothesis

There is no relationship between the diversity of a company's executive leadership and the following factors: (C1) CEO gender; (C2) CEO ethnicity; (C3) CEO age; (C4) Length of time as CEO; (C5) CEO political affiliation; (C6) Company's geographic location; (C7) Number of employees; (C8) Company's industry sector; and the (C9) CEO's highest education degree achieved.

Alternate Hypothesis

There may well be a relationship between the diversity of a company's executive leadership and the following factors: (C1) CEO gender; (C2) CEO ethnicity; (C3) CEO age; (C4) Length of time as CEO; (C5) CEO political affiliation; (C6) Company's geographic location; (C7) Number of employees; (C8) Company's industry sector; (C9) CEO's highest education degree achieved.

4. Research Design And Methodology

Data

The population is defined as the Forbes published list of the 2016 Fortune 500 companies. Data from a random sample of two hundred and fifty Fortune 500 companies was collected. Due to the low percentage of Female CEO's represented within the random data, all fifty-five companies led by a female CEO within the Fortune 1000 were added to the sample data resulting in two hundred and ninety one companies analyzed. For the sample size to be statistically significantly with at least a confidence level of 95% and a margin of error of 5%, the sample size needed to be a minimum of two hundred and eighty companies.

Definition of Variables

Dependent Variable: A New Diversity Index (executive leadership level of diversity) was calculated for each company contained within the samples. The definition of the level of executive diversity used for this study is the extent to which an executive leadership team is anything other than a white male. Therefore, the New Diversity Index formula utilizes the number of executives along with their gender and race/ethnicity. The result is a diversification percentage represented as a number between 0 and 1 (0% diversification to 100% diversification). For example, if the entire executive leadership team is white males, the associated diversification index would be 0.0. In contrast, if the entire executive team is non-white females, the associated diversity index would be 1.0.

Independent Variables:

C1: CEO gender
C2: CEO ethnicity
C3: CEO age
C4: Length of time as CEO
C5: CEO political affiliation (Democrat or Non-Democrat)
C6: Company's geographic location (Region)
C7: Number of employees
C8: Company's industry sector
C9: CEO's highest education degree achieved

One-way ANOVA & Multiple Linear Regression Model Analysis

Due to the large amount of categorical independent variables, a One-way ANOVA (Analysis Of Variance) along with Multiple Linear Regression models was needed to reduce the number of independent variables. Analysis of the ANOVA results needed to include the P-Value, F-Value, Means and R2. A Multiple Linear Regression Model is also needed on all independent variables and requires VIF, P-Value, R2 and F-Values. The VIF is needed to determine if multi-collinearity existed between any of the independent variables. Independent variables with a high P-Values and low F-Value need to be flagged for removal from further models.

5. Analysis and Results

Exercise Model/Descriptive Statistics

Anova

A One-way ANOVA test was performed for each individual categorical variable. P-Value, F-Value, and R-sq was noted for each variable. Additional results taken into consideration were N and the Means. The level of significance for these tests is α of 0.05. Figure 1 shows the results indicating that the independent variables tested fell into one of three categories: Strong Possible Inclusion, Strong Possible Exclusion; and Further Analysis Needed. ANOVA results indicated that three variables showed a strong correlation to the dependent variable; the other variables showed no significant correlation or a weak possible correlation.

One-way ANOVA Results

Diversity Rate Versus:

	CEO Gender	CEO Ethnicity	Years CEO	Political Affiliation	Company Region	Company Ind. Sector	CEO Ed. Degree
P-Value	0.000	0.035	0.293	0.000	0.015	0.101	0.006
F-Value	19.81	4.48	1.11	12.70	3.52	1.86	7.80
R-sq	6.41%	1.53%	0.38%	4.21%	3.55%	3.17%	2.63%

	Strong Possible Inclusion
	Strong Possible Exclusion
	Additional Analysis Needed

Figure 1. One-Way ANOVA Results

Regression Model Results

A Multiple Linear Regression model was next performed utilizing all the independent variables. Analysis of the results from this Multiple Linear Regression Model (Figure 2) included Variable Inflation Factor (VIF), P-Value, R-sq, Means and F-Value. VIF was examined to determine if multi-collinearity existed between independent variables. A VIF value of 5 was used as a rejection criteria. However, all

independent variables had a VIF under 3. Therefore, none of the independent variables was excluded based upon VIF. Independent variables with high P-Values and low F-Values were noted for possible exclusion. A combination of the One-way ANOVA and the regression model results were used to identify the variables that should be removed from further models. Additional forward selection and backward elimination test were performed resulting in six of the nine independent variables being eliminated from the model. The results of those tests are seen in Figure 2.

Regression Analysis (All Variables): Diversity Index versus CEO Age, Number of Employees, CEO Gender, CEO Ethnicity, Length of time as CEO, Dem (political affiliation), Company Region, Doctorate Degree (Highest Education Degree), Sector (Industry sector). This regression analysis suggested that six of the nine independent variables were potential candidates for exclusion from the model.

	Regression Model	CEO Age	# of Employees	CEO Gender	CEO Ethnicity	Years CEO	Political Affiliation	Company Region	Company Ind. Sector	Highest Ed. Degree
P-Value	0.000	0.608	0.662	0.000	0.051	0.400	0.004	0.076	0.111	0.104
F-Value	3.52	0.26	0.19	20.87	3.83	0.71	8.27	2.31	1.81	2.66
VIF		1.21	1.14	1.09	1.14	1.16	O 1.20	≤ 1.63	≤ 2.14	1.12
R-sq	16.11%									

	Strong Possible Inclusion
	Strong Possible Exclusion
	Additional Analysis Needed

Figure 2. Regression Results (all independent variables)

Further analysis was performed for CEO Ethnicity and Company Region by removing the other insignificant variables from the regression model. The next Regression Analysis regressed Diversity Index versus CEO Gender, CEO Ethnicity, Dem (political affiliation), and Company Region. The results are shown in Figure 3. The results of those tests are seen in Figure 3.

	Regression Model	CEO Gender	CEO Ethnicity	Political Affiliation	Company Region
P-Value	0.000	0.000	0.091	.004	0.114
F-Value	6.32	20.65	2.88	8.40	2
VIF		1.04	1.08	1.09	≤ 1.54
R-sq	11.78%				

	Strong Possible Inclusion
	Strong Possible Exclusion

Figure 3. Regression Results (reduced set of independent variables)

Due to conflicting results between ANOVA and the regression tests, Multiple Linear regression tests including forward selection and backward elimination needed to be performed on the remaining four independent variables. Specifically, to ensure that CEO Ethnicity and Company Region should be eliminated from the model, further analysis was performed using Backward and Forward regression. These tests included CEO Gender, CEO Political Affiliation (DEM), CEO Ethnicity and Company Region. Both CEO Ethnicity and Company Region were eliminated using a level of significance of .05 (Figure 4).

	Regression Model	CEO Gender	CEO Ethnicity	Political Affiliation	Company Region
P-Value	0.000	0.000	Removed	0.004	Removed
F-Value	14.28	20.31		8.28	
VIF		1.03		1.03	
R-sq	9.02%				

Figure 4. Regression Results (backward elimination of terms)

At this point in the analysis it was observed that a significant number of outliers seemed to exist in the data. This was troubling so further analysis was performed by removing these outliers (38 data points or 13%) and viewing the results (see Figure 5). One outlier remained within the boxplot. Any further reduction did not improve the model. These results further indicated that CEO Ethnicity should be removed from the model. However, Company Region now came into the level of significance.

Regression Analysis: Diversity Index versus CEO Gender, CEO Ethnicity, Dem (political affiliation), Company Region, CEO Ethnicity

	Regression Model	CEO Gender	CEO Ethnicity	Political Affiliation	Company Region
P-Value	0.000	0.000	0.292	0.000	0.001
F-Value	9.4	18.50	1.12	20.74	5.35
VIF		1.05	1.08	1.09	≤ 2.07
R-sq	18.59%				

Figure 5. Regression Results (with removal of outliers)

A final model was run with Diversity Index versus the three remaining independent variables: CEO Gender, CEO Ethnicity, Dem (political affiliation), and Company Region. (See Figure 6).

	Regression Model	CEO Gender	Political Affiliation	Company Region
P-Value	0.000	0.000	0.000	0.007
F-Value	9.4	16.03	12.59	4.13
VIF		1.05	1.10	≤ 1.99
R-sq	17.73%			

Figure 6. Regression Results (outliers removed)

Lastly, a forward regression test (α to enter = 0.05) was conducted that included CEO Gender, CEO Political Affiliation (DEM), and Company Region. The small Mallows' Cp value indicates that the model is relatively precise (has small variance) in estimating the true regression coefficients and predicting future responses. In addition, the Mallows' Cp value is close to the number of predictors indicating that the model is relatively unbiased in estimating the true regression coefficients and predicting future responses. See Figure 7.

	Step 1	Step 2	Step 3
Political Affiliation P-Value	0.000	0.000	0.000
CEO Gender P-Value		0.001	0.000
Company Region P-Value			0.007
R-sq	9.14%	13.72%	**17.73%**
Mallows' Cp	24.53	12.38	**6.00**

Figure 7. Regression Results (final results)

Note- Boxplots of Independent Variables can be seen in the attachment

6. Conclusions

The research contained within this paper is focused on determining if there is a relationship between the dependent variable Diversity Index, and the independent variables (C1) CEO gender; (C2) CEO ethnicity; (C3) CEO age; (C4) Length of time as CEO; (C5) CEO political affiliation; (C6) Company's geographic location; (C7) Number of employees; (C8) Company's industry sector; (C9) CEO's highest education degree achieved.

It was concluded that the level of diversity within a company's executive leadership may well be related to the gender of the CEO, the location of the company as well as the CEO's political affiliation. Specifically, using the final model the highest level of diversity within the executive leadership of the firm appears to exist when the CEO is female, a democrat, and the company is located in the West region of the United States.

The final model is shown in the equation below:

Regression Equation:

New Diversity Rate = 0.2455 + 0.0 CEO Gender Female - 0.0449 CEO Gender Male + 0.0 Dem_D - 0.03370 Dem_Other - 0.0420 Company Region Midwest - 0.0184 Company Region Northeast - 0.0356 Company Region South + 0.0 Company Region West

7. Recommendations

Future Research needs to revisit prior studies surrounding Executive Leadership diversification. Researchers should look for studies that include the following: (a) Gender of the CEO; (b) CEO's highest level of education, to include the University/College attended; (c) CEO's political affiliation; (d) Total count of male and females that make up the executive leadership team; and (e) Ethnicity of the executive leadership team. Additionally, important data should be collected that includes the name of the organization; the industry, sector, or both; and the geographical region where the primary operations is domiciled or its headquarters.

Further research and data analysis should be done on all Executive Staff and Senior Leaders (ESSL). For the purposes of collecting data it should include: (a) an expanded data set that includes the full Fortune 1000 firms; (b) data tables to include "white male" indicators; (c) a modified diversity index utilizing the percentage of white males as the index; (d)a comparison of the executive leadership diversity index against graduating classes for various time periods; (e) an evaluation of the ratios while looking for trends; and lastly (f) the age of the CEO and their higher education graduating year should be evaluated.

Corporations should review company diversity statements and compare them to the diversity ratio of the executive leadership team. They should acknowledge and embrace differences through continued training exercises. Lastly, firms should search for biases and evaluate hiring practices to determine if there are homogeneous trends.

Researchers should continue to track graduation trends, especially in the areas of ethnicity, ethnicity, sex, age, and the highest level of education achieved by executives. They should compare the average age of CEO and his/her approximate graduation year with the graduation percentages of ethnicity, sex, age, highest level of education. Lastly, they should determine if a higher percentages of non-white and other graduation rates influence more diversity in the executive leadership team. In that regard the following table is of note and could be expanded on in future research.

1986 and 2015 Graduation Percentage

Year	White		Black		Hispanic		Asian	
	Male	Female	Male	Female	Male	Female	Male	Female
1986	24.1	22.9	10.1	13.3	Unknown	Unknown	Unknown	Unknown
2015	33.2	40.3	16.5	24.2	14.5	18.5	62.8	67.2

Figure 8. Graduation Results by Ethnicity (1986 and 2015)

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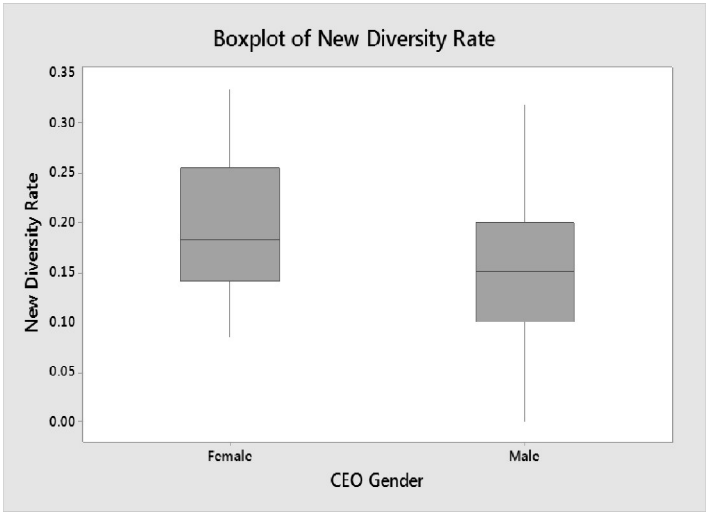
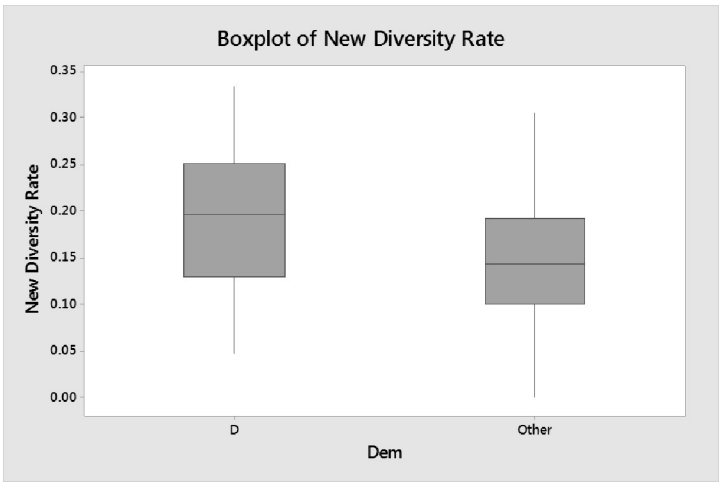
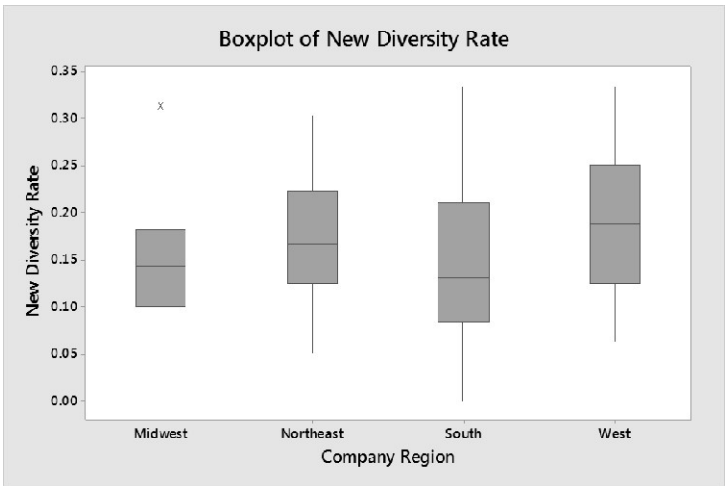
9. Attachment

Box Plots for the three major independent variables







A Comparison of Classical Transportation Models

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Abstract

As is well known, the assignment model is a special case of the general transportation model. The general transportation problem, of course, belongs to the linear class of mathematical programming problems. Before the availability of modern computers and software to solve such linear programming problems, manual algorithms were developed for solving such problems as the assignment problem. Four such algorithms were in common usage: The Northwest Corner Method, the Least Cost Method, Vogel's Approximation Method, and the Hungarian Method. In this paper we explain and analyze each of these methods and attempt to formulate a common theoretical basis for the **Method of Multipliers** and the **Hungarian Method**.

1. Introduction

The science of mathematical programming has literally transformed the whole field of business. Indeed, it is not too much to say that most, if not all, of the really important problems in business could not be adequately solved before the advent of mathematical programming. Although a great deal of foundational work preceded the formal development of mathematical programming, the science of mathematical programming has its origins back in the 1940s. The two divisions of mathematical programming that have developed are non-linear and linear programming, but the initial work was done in linear programming, by such researchers as Dantzig, von Neumann, Kantorovich, Leontief, and Koopmans. It was George B. Dantzig who was the first to formalize linear programming as a discipline in 1947.

Mathematical programming is known in applied mathematics as a branch of constrained optimization. In constrained optimization, a function is optimized, which is to say maximized or minimized, subject to a set of constraints. The constraints limit the range within which a solution can be found. Among early mathematicians it seems as though the French mathematician Gaspard Monge was the first to anticipate linear programming (Monge, 1781), who considered it with reference to the transportation problem. However, the first serious investigation was done by another French mathematician, J. B. J. Fourier, who developed Fourier series. Fourier wrote the first paper known on linear programming in 1823 (Dantzig, 2002). Only the abstract of this paper seems to have survived as a part of another paper that Fourier wrote later on the solution of inequalities (Fourier, 1826). Another such early mathematician to make a contribution was Pouissant who wrote a paper describing linear programming methods (Pouissant, 1911). After Pouissant's contribution, very little advancement was made in linear programming until 1939, when the great Russian mathematician, Leonid V. Kantorovich wrote a remarkable paper for that time on the application of linear programming in production planning (Kantorovich, 1939). Two years later, the mathematician Frank Hitchcock made a significant contribution by formulating and solving the transportation problem in 1941 (Hitchcock, 1941).

In 1947 George Danzig was working on a project for the U. S. Air Force which involved a time-phased

planning model. The mathematical model that Danzig formulated for this problem, turned out to be to a very large model, which would be described today as a time-staged, dynamic linear program. In order to solve this problem, Danzig devised the approach which has become known as the **Simplex Method**. With the Simplex Method, a linear function called the objective function is optimized, that is to say maximized or minimized, subject to a set of linear constraints. Linear in this context means that there are no powers or products of variables either in the objective function or the constraints. Now it is obvious that the manual solution of constrained linear programming problems of any considerable size would require prohibitive amounts of time and effort. Danzig makes the point that about this time the computer entered the scene and made the solution of very large constrained optimization very practicable (Danzig, 2002).

Since those early days, the field of mathematical programming has grown almost exponentially. Soon after the pioneering work of Danzig in linear optimization was firmly established, investigations began into non-linear programming. These, along with the rapidly increasing power of computers, have led to powerful solution methods for very complex optimization problems (Lasdon and Waren, 1983).

2. Literature Review

One of the most important classes of linear optimization problems is the **Transportation Problem**. Although the Japanese mathematician Professor Soichi Kakeya solved a version of the **Transportation Problem** as early as 1917 (Kakeya, 1917), it was first solved in its most general form by the American mathematician, Frank L. Hitchcock, as mentioned above. Prior to the advent of high speed computers, it was necessary to solve the **Transportation Problem** manually, and a number of manual methods, were developed, generally iterative, to solve the problem. These methods will be discussed in the following paragraphs.

2.1. Northwest Corner Method

The **Northwest Corner Method** obtains its name from the fact that the initial basic feasible solution is obtained by starting in the upper left-most cell of the transportation tableau, and assigning the initial shipment quantities in such a way as to satisfy all of the constraints. It is not properly a method for solving the **Transportation Problem**, but rather a method for obtaining an initial basic feasible solution (Charnes and Cooper, 1954). It is used as the first step in moving toward an optimal solution. An example of the N**orthwest Corner Method** is shown below in **Figure 1**.

Total cost = $67,000 *Optimal cost* = $42,000

		Destination				Total supply	Used supply	Unused supply
		1	2	3	4			
Supply sources	1	80 / 200	50 / 100	30	60	300	300	0
	2	20	60 / 200	40 / 200	50	400	400	0
	3	50	40	70 / 200	40 / 300	500	500	0
	Demand	200	300	400	300			
	Satisfied demand	200	300	400	300			
	Unsatisfied demand	0	0	0	0			

Figure 1: Initial Basic Feasible Solution Using the Northwest Corner Method

2.2. Least Cost Method

The **Least Cost Method**, as was the case with the **Northwest Corner Method**, is not properly a method

for solving the **Transportation Problem**. Rather, it is also a method for obtaining an initial basic feasible solution. With the **Least Cost Method**, an initial basic feasible solution is obtained by locating the least cost for satisfying the demand at destination #1, and assigning all of the supply available at that cost. This process is continued for each destination, always assigning all of the supply available at the least cost until all of the constraints are satisfied. An example of the **Least Cost Method** is shown below in **Figure 2**.

Total cost = $42,000 *Optimal cost* = $42,000

		Destination				Total supply	Used supply	Unused supply
		1	2	3	4			
Supply sources	1	80	50	30 300	60	300	300	0
	2	20 200	60	40 100	50 100	400	400	0
	3	50	40 300	70	40 200	500	500	0
	Demand	200	300	400	300			
	Satisfied demand	200	300	400	300			
	Unsatisfied demand	0	0	0	0			

Figure 2: Initial Basic Feasible Solution Using the Least Cost Method

It should be noticed that in this case, the initial basic feasible solution obtained from the **Least Cost Method** turns out to be the optimal solution. This does not usually turn out to be the case.

2.3. Stepping Stone Method

The **Stepping Stone Method** employs an initial basic feasible solution, obtained from a method such as those discussed above, and moves through successive iterations of feasible solutions, toward an optimal solution. This is done by adding 1 unit of supply to the least cost source for destination #1 that is not in the basic feasible solution, and then deducting 1 unit of supply from that assigned in the initial basic feasible solution. Then, a new basic feasible solution is constructed by forming a closed loop in which +1 unit is added, followed by -1 unit in order to ensure that all constraints remain satisfied. Then, once the closed circuit has been constructed, a new objective function value is computed. If the objective value has decreased, then as much of the new supply as is available in the initial column is assigned to satisfy the demand for that column. If no decrease in the objective function occurs, or if an increase occurs, then no reassignment is made. In either case, a new cell is selected to which a +1 is added. Then a new circuit is constructed, and the entire process. This process is continued until there are no more opportunities to decrease the value of the objective function. At this point an optimal solution has been obtained (Hadley, 1963). **Figure 3** below show a typical tableau for the **Stepping Stone Method**.

Total cost = $60,950 *Optimal cost* = $42,000

		Destination				Total supply	Used supply	Unused supply
		1	2	3	4			
Supply sources	1	50 299	80	30 1	60	300	300	0
	2	40 1	50 200	70 199	40 100	500	500	0
	3	60	20	40 200	50 200	400	400	0
	Demand	300	200	400	300			
	Satisfied demand	300	200	400	300			
	Unsatisfied demand	0	0	0	0			

Figure 3: Example tableau for the Stepping Stone Method

2.4. Vogel's Approximation Method

Vogel's Approximation Method is another frequently used approach to obtaining an optimal solution once an initial basic feasible solution has been obtained from a method such as **Northwest Corner** or **Least Cost. Vogel's Approximation Method** is based upon the calculation of what might be termed a penalty cost for each source and destination in the tableau (Hillier and Lieberman, 1969). An example of **Vogel's Approximation Method** is shown in **Figure 4** below.

Total cost = $0 *Optimal cost* = $42,000

		Destination				Total supply	Used supply	Unused supply	Row difference
		1	2	3	4				
Supply sources	1	80	50	30	60	300	0	300	20
	2	20	60	40	50	400	0	400	20
	3	50	40	70	40	500	0	500	0
	Demand	200	300	400	300				
	Satisfied demand	0	0	0	0				
	Unsatisfied demand	200	300	400	300				
	Column Difference	30	10	10	10				

Figure 4: Vogel's Approximation Method

2.5. Method of Multipliers

The **Method of Multipliers** begins with an initial basic solution obtained from **Northwest Corner** or **Least Cost,** as with **Stepping Stone** and **Vogel's Approximation**. It then employs a decomposition of the unit shipping costs into two cost components. The first is a characteristic cost for each source, and the second is a characteristic cost for each destination. The costs are then used to calculate what might be called an opportunity cost (Taha, 2003). This method is discussed more fully in **Section 3**.

2.6. Assignment Problem and Hungarian Method

The **Assignment Problem** is a special case of the **Transportation Problem** in which several resources, such as persons or machines, are assigned to perform several tasks. If the number of resources is equal to the number of tasks to be performed, the problem is said to be balanced. In this case, there is a 1 to 1 assignment of resources to tasks. That is to say, each resource has one and only one task, and each task has one and only one resource. A classical approach to solving is one called the **Hungarian Method.** This method was named after two Hungarian mathematicians, D. König and E. Egerváry, by Harold W. Kuhn who discovered it (Kuhn, 1955). This also is discussed more fully in **Section 3.**

3. Methodology

As noted above, one of the most useful applications to be developed from linear programming theory was the Transportation Model. For the purposes of the following discussion, an example of this model was shown above in **Figure 1**.

With the classical **Transportation Model**, a certain amount of total supply is available, and a certain amount of demand must be satisfied. The demand to each destination is satisfied by the supply from each source at a characteristic cost. We say a characteristic cost because it the expense incurred in

shipping 1 unit from source *m* to destination *n*, and no two unit shipping costs are *necessarily* the same. In Figure 1 above, these characteristic unit costs are shown in italics in the smaller, upper right-hand squares of the larger squares. The bold-face numbers, just below the smaller squares, are the amounts to be shipped from source *m* to destination *n*.

The objective of this analysis is to minimize the total transportation cost, and the amounts shown are those which minimize the total transportation cost. The amount of $67,000, shown at the top-left of Figure 1, is that obtained by assigning an initial, basic, feasible solution using the Northwest Corner Method. The cost of $42,000, shown in the upper-right corner of Figure 1, is the optimal cost that would be obtained from using one of the optimization methods.

3.1. The Transportation Problem and the Method of Multipliers

Once a basic, feasible solution has been obtained, then it is possible to use an optimization method, such as Vogel's Approximation Method (VAM), or Method of Multipliers (MoM) to obtain the optimal solution. In either case, the optimizal solution is obtained through successive approximations. For the purposes of this paper, we have chosen to use MoM. **Figure 5** below shows the first stage in the successive application of MoM that would eventually lead to an optimal solution.

Total cost = $67,000 *Optimal cost* = $42,000

		Destination 1	2	3	4	Total supply	Used supply	Unused supply	*u*
Supply sources	1	*80* **200**	*50* **100**	*30*	*60*	300	300	0	0
	2	*20*	*60* **200**	*40* **200**	*50*	400	400	0	10
	3	*50*	*40*	*70* **200**	*40* **300**	500	500	0	40
	Demand	200	300	400	300				
	Satisfied demand	200	300	400	300				
	Unsatisfied demand	0	0	0	0				
	v	80	50	30	0				

Non-basic variables	c_{ij}	u_i	v_j	$u_i+v_j-c_{ij}$
X_{13}	30	0	30	0
X_{14}	60	0	0	-60
X_{21}	20	10	80	70
X_{24}	50	10	0	-40
X_{31}	50	40	80	70
X_{32}	40	40	50	50

X_{11}	X_{12}	X_{13}	X_{14}	X_{21}	X_{22}	X_{23}	X_{24}	X_{31}	X_{32}	X_{33}	X_{34}
0	0	0	-60	*70*	0	0	-40	*70*	*50*	0	0

Figure 5: Example Method of Multipliers Tableau

Now, in using the MoM, it is necessary to think of each unit transportation costs as being composed of two *characteristic* components: The first component is associated with the particular row in which a unit cost appears, and the second is component associated with the particular column in which the unit cost appears. Then, if the characteristic component for each row is designated as u_i, where i = 1, 2, 3 for our example, and the characteristic component for each column as v_j, where j = 1, 2, 3, 4, then each of the unit transportation costs involved in the basic feasible solution, designated as c_{ij}, can be written as $c_{ij} = u_i + v_j$. Thus, using c_{23} for example, c_{23} can be expressed as $c_{23} = u_2 + v_3$. Using this relationship for each c_{ij}, it is then possible to solve for each u_i and each v_j, for those variables, x_{ij}, in the basic feasible solution. Further, using the relationship $u_2 + v_3 - c_{23}$ it is possible to calculate what amounts to an opportunity cost for those variables not currently in the basis.

Now it will be observed that we begin the MoM process using the initial, basic, feasible solution obtained using the Northwest Corner Method. For our application there are seven unknowns: three u_i, one for each row, and four v_j, one for each column. Further, the initial basic, feasible solution obtained with the Northwest Corner Method occupies six of the twelve cells in the Figure 2 tableau. Consequently,

there are six cells that are not in the basic, feasible solution. The question is which of the current basic variables should be moved out of the basic feasible solution, and which in, so that the total transportation cost decreases toward optimality. This question is answered by calculating the value of $u_i + v_j - c_{ij}$. The magnitude of this value may be thought to indicate the penalty to the total transportation cost for not using a basic, feasible solution involving the non-basic variable under consideration. The penalty cost for each such non-basic variable is shown in the right most column of **Figure 5**. These values, along with those for basic variables, are arrayed in the row at the bottom of **Figure 5**. It should be noticed from this row that the penalty costs for the variables currently in the basis are all 0. This means, of course that no penalty is incurred for these variables because they are currently in the basis.

The decision as to which variable will enter the basis is made according to which variable has the greatest penalty. It will be seen from **Figure 5** that there are two variables having a penalty value of 70, x_{21} and x_{31}. The tie is broken by choosing variable x_{21} because it has the lower of the two transportation costs. Moving x_{21} into the basis and rebalancing supply and demand to satisfy constraints, results in the new tableau shown in **Figure 6** below.

Total cost = $67,000 *Optimal cost* = $42,000

		Destination 1	2	3	4	Total supply	Used supply	Unused supply	u
Supply sources	1	80 / 200	50 / 100	30	60	300	300	0	0
	2	20	60 / 200	40 / 200	50	400	400	0	10
	3	50	40	70 / 200	40 / 300	500	500	0	40
	Demand	200	300	400	300				
	Satisfied demand	200	300	400	300				
	Unsatisfied demand	0	0	0	0				
	v	80	50	30	0				

Non-basic variables	c_{ij}	u_i	v_j	$u_i+v_j-c_{ij}$
x_{13}	30	0	30	0
x_{14}	60	0	0	-60
x_{21}	20	10	80	70
x_{24}	50	10	0	-40
x_{31}	50	40	80	70
x_{32}	40	40	50	50

x_{11}	x_{12}	x_{13}	x_{14}	x_{21}	x_{22}	x_{23}	x_{24}	x_{31}	x_{32}	x_{33}	x_{34}
0	0	0	-60	*70*	0	0	-40	*70*	*50*	0	0

Figure 6: Method of Multipliers Tableau after First Iteration

It should be noticed in Figure 3 above that the total cost has decreased by $14,000 after the first iteration. This amount is the product of the $70/ unit penalty and the 200 units now to be shipped from Supply Source 2 to Destination 1. Successive iterations using the MoM approach will eventually yield the optimal solution. Optimality will have been reached when the penalty values for each of the non-basic variables have become either "0" or negative. At this point, the Total Cost would equal the Optimal Cost of $42,000.

3.2. The Assignment Problem and the Hungarian Method

The **Assignment Problem** is a special case of the **Transportation Problem** and is used for applications in which several tasks are to be performed, and several entities are available to perform those tasks. In general, the entities performing the tasks need not be equal to the number of tasks to be performed. For the purposes of this discussion, however, it will be assumed that the number of tasks to be performed equals the number of entities available to perform the tasks. Then, if "m" is the number of entities to perform the tasks, and "n" is the number of tasks to be performed, this discussion will assume that m = n. Thus, the final solution will involve a 1 to 1 relationship between entities and tasks, viz, every entity will have a task to perform, and every task will have and entity to perform it. Once the assignments are made, each row will contain only a single 1, and each column will have only a single 1. The assignment of entities

to tasks is done in such a way as to minimize some resource such as time or cost. An example of an assignment problem is shown in **Figure 7** below.

Total time = 100 hrs

		Project				Total
		1	2	3	4	supply
Employee	1	50	80	30	60	1
	2	40	50	70	40	1
	3	60	20	40	50	1
	4	20	40	30	10	1
	Demand	1	1	1	1	

		Project				Total	Used	Unused
		1	2	3	4	supply	supply	supply
Employee	1	0	0	1	0	1	1	0
	2	1	0	0	0	1	1	0
	3	0	1	0	0	1	1	0
	4	0	0	0	1	1	1	0
	Demand	1	1	1	1			
	Satisfied demand	1	1	1	1			
	Unsatisfied demand	0	0	0	0			

Figure 7: Example Assignment Problem

In the above example, 4 employees are available to perform 4 projects. The assignment of employees to tasks is to be performed so that the total time required to complete all 4 tasks is minimized. The assignment could also have been done with the objective of minimizing cost.

Before the advent of modern computers, Assignment Problems were often solved using an approach known as the **Hungarian Method**. This method employs a sequence of row reductions and column reductions to the cost matrix to arrive at an optimal solution. The **Hungarian Method** is shown below in **Figure 8** and explained in the following paragraph.

1

		Project				Total
		1	2	3	4	supply
Employee	1	50	80	30	60	1
	2	40	50	70	40	1
	3	60	20	40	50	1
	4	20	40	30	10	1
	Demand	1	1	1	1	

2

		Project				Total
		1	2	3	4	supply
Employee	1	50	80	*30*	60	1
	2	*40*	50	70	40	1
	3	60	*20*	40	50	1
	4	20	40	30	*10*	1
	Demand	1	1	1	1	

3

		Project				Total
		1	2	3	4	supply
Employee	1	20	50	*0*	30	1
	2	*0*	10	30	*0*	1
	3	40	*0*	20	30	1
	4	10	30	20	*0*	1
	Demand	1	1	1	1	

4

		Project				Total
		1	2	3	4	supply
Employee	1	20	50	*0*	30	1
	2	*0*	10	30	*0*	1
	3	40	*0*	20	30	1
	4	10	30	20	*0*	1
	Demand	1	1	1	1	

5

		Project				Total
		1	2	3	4	supply
Employee	1	20	50	*0*	30	1
	2	*0*	10	30	*0*	1
	3	40	*0*	20	30	1
	4	10	30	20	*0*	1
	Demand	1	1	1	1	

Total time = 100 *hrs*

6

		Project				Total
		1	2	3	4	supply
Employee	1			1		1
	2	1				1
	3		1			1
	4				1	1
	Demand	1	1	1	1	

Figure 8: Hungarian Method applied to the Transportation Problem

To solve the **Assignment Problem** using the **Hungarian Method**, it is necessary to perform a series of row and column reductions to the cost matrix. The original cost matrix for our example is shown in panel 1 in **Figure 8** above. The first step is to locate the smallest unit cost in the first row, and to deduct it from each of the other unit costs in the first row. This value is 30, shown in italic type face in panel 2, and the results of this reduction are shown in panel 3. Similar row reductions for rows 2, 3, and 4 result in the remaining values in panel 3. Next, column reductions are performed on the reduced cost matrix in panel 3. As with row reductions, the minimum value in each column is selected, and is deducted from each of

the values in its column. In this case, the minimum value in each column is "0," so that the reduced cost matrix remains unchanged after the column reduction. This result in shown in panel 4 of Figure 5.

Next, it is necessary to perform a test to determine whether the optimal solution has been reached. This is done by "covering" all of the "0s" in the reduced cost matrix. If the total number of lines required to "cover" all of the "0s" is less than the number of rows (or columns) in the cost matrix, then it is necessary to perform further operations on the cost matrix until the minimum number of lines required is equal to the number of rows in the cost matrix. In this example, the number of lines required equals the number of rows, indicating that the optimal solution has been reached. This result is shown in panel 5 above.

The last step in using the **Hungarian Method** is to obtain the solution matrix. This is done by removing all numbers in the cost matrix except the "0s." Then the "0s" in the solution matrix are replaced by "1s" in such a way that each row has only a single "1," and each column has only a single "1." This operation results in the final solution shown in panel 6. Finally, multiplying the solution matrix by the original cost matrix in panel 1 will result in the solution. This solution, 100 hours, is shown in the center- right of **Figure 8**.

3.3. The Common Theoretical Basis Between MoM and the Hungarian Method

Now it will be observed that optimal solutions are obtained for both **MoM** and the **Hungarian Method** by partitioning the unit costs in the cost matrices of each into two components. This raises the question of whether **MoM** and the **Hungarian Method** can be shown to have a common theoretical basis. It is to this problem that we turn next. The following analysis is devoted to answering this question. The standard **Transportation Problem** can be written in the following form:

$$Min\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{i,j} * x_{i,j}$$

Subject to …

$$\sum_{j=1}^{n} x_{i,j} \le a_i \quad \text{for i = 1, 2, ... , m}$$

and …

$$\sum_{i=1}^{m} x_{i,j} = b_j \quad \text{for j = 1, 2, ... , n}$$

$$x_{i,j} \ \ge\ 0 \quad \text{for all i and j}$$

Further, the constraints in the **Transportation Problem** can be rewritten as …

$$a_i - \sum_{j=1}^{n} x_{i,j} = 0$$

and …

$$b_j - \sum_{i=1}^{m} x_{i,j} = 0$$

Now, since both equations are equal to zero, any multiple of either will also equal zero. Then, …

$$u_i * \left[a_i - \sum_{j=1}^{n} x_{i,j} \right] = 0 \qquad \text{and also} \qquad v_j * \left[b_j - \sum_{i=1}^{m} x_{i,j} \right] = 0$$

Where $\mathbf{u}_i$ and $\boldsymbol{v}_j$ are constants. Continuing, we can write …

$$Min\ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{i,j} * x_{i,j} - \sum_{i=1}^{m} u_i * \left[a_i - \sum_{j=1}^{n} x_{i,j} \right] - \sum_{j=1}^{n} v_j * \left[b_j - \sum_{i=1}^{m} x_{i,j} \right]$$

Now for each basic variable …

$$c_{i,j} - u_i - v_j = 0$$

Then at minimum Z, …

$$\sum_{i=1}^{m} \sum_{j=1}^{n} (c_{i,j} - u_i - v_j) * x_{i,j} = 0$$

Consequently, …

$$\text{Min Z} = \sum_{i=1}^{m} u_i * a_i + \sum_{i=1}^{n} v_j * b_j$$

The above expression is true for general **Transportation Problem**. Thus, for the general **Transportation Problem**, the two equations above disclose that each of the costs in the matrix of transportation costs can be partitioned into two components, one characteristic of a unit shipping cost for each source of supply, and the other characteristic of a unit shipping cost to each destination. This determination is expressed by the first of the two equations above. Further, the optimal solution can be computed by summing the products of each characteristic unit shipping cost and the corresponding shipping capacity; then adding to that sum a second sum involving the products of a characteristic unit shipping cost for each destination and the corresponding amount shipped to that destination. This very important result is expressed by the second of the two equations above.

Now, turning to the **Assignment Problem, it** is a special case of the general T**ransportation Problem.** Thus, the second equation above is also true for the **Assignment Problem** in which a_i and b_j = 1. Then for the **Assignment Problem** …

$$\text{Min Z} = \sum_{i=1}^{m} u_i * (1) + \sum_{i=1}^{n} v_j * (1) \qquad \text{or ...} \qquad \text{Min Z} = \sum_{i=1}^{m} u_i + \sum_{i=1}^{n} v_j$$

Further, for the **Assignment Problem**, a new modified matrix can be obtained by subtracting two constants from each element of the original cost matrix, the first constant characteristic of each row or source, and the second constant characteristic of each column or demand. This is expressed by the equation below.

$$c'_{i,j} = c_{i,j} - u_i - v_j$$

Then, using this equation, a transformed objective function, $c'_{i,j}$, can be written as …

$$\sum_{i=1}^{m} \sum_{j=1}^{n} c'_{i,j} * x_{i,j} = \sum_{i=1}^{m} \sum_{j=1}^{n} (c_{i,j} - u_i - v_j) * x_{i,j}$$

and …

$$\sum_{i=1}^{m} \sum_{j=1}^{n} c'_{i,j} * x_{i,j} = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{i,j} * x_{i,j} - \sum_{i=1}^{m} \sum_{j=1}^{n} u_i * x_{i,j} - \sum_{i=1}^{m} \sum_{j=1}^{n} v_j * x_{i,j}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} u_i * x_{i,j} = \sum_{i=1}^{m} u_i * \sum_{j=1}^{n} x_{i,j} = \sum_{i=1}^{m} u_i * (1) = \sum_{i=1}^{m} u_i = \text{Constant}_1$$

Similarly, for v_j ...

$$\sum_{i=1}^{m}\sum_{j=1}^{n} v_j * x_{i,j} = \sum_{j=1}^{n} v_j * \sum_{i=1}^{m} x_{i,j} = \sum_{j=1}^{n} v_j *(1) = \sum_{j=1}^{n} v_j = \text{Constant}_2$$

Finally, …

$$\sum_{i=1}^{m}\sum_{j=1}^{n} c'_{i,j} * x_{i,j} = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{i,j} * x_{i,j} - \text{Constant}_3$$

Thus, in general, the double sum on the left differs from the double sum on the right by only a constant. If this is true in general, then it is true at the optimal solution. Put differently, the optimal solution for the **Assignment Problem** can be obtained by subtracting a single constant from each of the elements in the original matrix of unit resources. This constant is again, as it was for the **Transportation Problem**, the sum of a characteristic unit resource component for each source, and a characteristic unit resource component for each demand. This resource may be cost or time or any other quantity that it is desirable to minimize.

4. Summary and Conclusion

In the development above an example problem was used to demonstrated that the **Method of Multipliers** may be used iteratively to arrive at an optimal solution for the **Transportation Problem**. It was observed that the **Method of Multipliers** employs a process in which each of the unit costs in the cost matrix is partitioned into two constants.

Next, the **Assignment Problem** was considered, and the **Hungarian Method** was applied to obtain a solution to the **Assignment Problem**. It was observed from this example that the **Hungarian Method** employs a process whereby the units resources in the resource matrix, whether these resources are time or cost or whatever, are also partitioned into a row component and a column component.

These results then prompted a question as to whether the **Method of Multipliers** and the **Hungarian Method** have a common theoretical basis**.** Thus, an attempted proof was undertaken to demonstrate a common theoretical basis for **Method of Multipliers** and the **Hungarian Method**. This resulted in a general proof that the **Method of Multipliers** arrives at an optimal solution for the **Transportation Problem** by partitioning the unit costs in the cost matrix into a row component, and a column component.

This was followed by a proof that the **Hungarian Method** solves the **Assignment Problem** by partitioning the unit resource constants in the unit resource matrix into a row, or source component, and a column, or demand, component. This partitioning is applied somewhat iteratively to eventually arrive at an optimal solution for the **Assignment Problem.**

In conclusion, the foregoing analysis has demonstrated that the **Method of Multipliers** and the **Hungarian Method** indeed have a common theoretical basis. Both methods employ a partitioning of the unit costs (in general unit resources) into a component for each row, or source, and a component for each column, or demand. In both methods, this partitioning approach leads to an optimal solution.

Authors' postscript: Some of the work in this paper was taken from other authors, and these authors have been credited in the Bibliography. However, the central contention of this paper, that the ***Method of Multipliers*** *and the* ***Hungarian Method*** *have a common theoretical basis, is new so far as the authors have been able to find. Considering the mathematical brilliance of the pioneers in the field of mathematical programming, those such as Danzig, von Neumann, Kuhn, and Tucker, it is inconceivable that one of them has not already discovered this relationship between these two methods. Notwithstanding, no such discovery by one of them was disclosed by the literature.*

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Cirkinemeter – A DIY Platform for Rotating Frames of Reference

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Abstract

Kinematics in rotating frames, a core topic of introductory physics, should be internalized by high school students through quantitative hands-on experiments. However, subtle concepts like non-inertial frames and the Coriolis acceleration are often taught qualitatively (if at all) because commercially available precision instruments that can measure these phenomena are prohibitively expensive. In this paper, we introduce the Cirkinemeter (Circular + Kinematics + Meter) that measures, with high precision, velocity and acceleration on a rotating disk. This classroom-tested instrument is built using Arduino microcontrollers, and is *affordable*, *customizable* and *open-sourced.*

The Cirkinemeter enables students to accurately measure and verify radial acceleration $|a_{radial}| = \omega^2 r$ by independent measurements of r, and ω; it measures also the direction of the radial acceleration, thus distinguishing between centripetal and centrifugal accelerations. Additionally, the Cirkinemeter demonstrates the kinematics under the Coriolis acceleration with qualitative and quantitative polar graphs that match the predictions of Steyn-Ross and Ivey. All parts of the Cirkinemeter are from open-source providers. The details of hardware, software, laser-cut designs, PCB designs and instructions on its assembly are available online. We strongly believe that the Cirkinemeter helps expanding the current movement of democratizing hands-on physics learning, by enabling students to build their own Cirkinemeters and seek their own data.

1. Introduction

Rotating frames of reference have been of interest to physics teachers and students alike for decades. The 1960's classic film "Frames of Reference" by Hume and Ivey (ETS, 1960), its theoretical explorations (Steyn-Ross, 1992) by Steyn-Ross and Ivey, and the 2013 MIT video "Rotating Frames of Reference" by Sarma (Sarma, 2014) explore this topic with memorable presentations. These presentations help viewers gain qualitative understanding. However, deeper quantitative insight, can only be obtained by hands-on experimentation. Unfortunately, commercially available instruments that can perform classroom-experiments on a rotating frame of reference are prohibitively expensive [(Pasco 208), (Vernier, 2018)]. See Section 8 for a detailed discussion. Additionally, these instruments do not measure an important consequence of rotating frames: kinematics under Coriolis acceleration.

This paper presents the Cirkinemeter (Circular + Kinematics + Meter): an affordable, portable, reliable, expandable platform to conduct experiments on rotating frames. At its core, the Cirkinemeter is a motor-controlled turntable that measures angular velocity with an IR photogate system. The Cirkinemeter uses an accelerometer apparatus to measure and publish instantaneous acceleration at any point on the rotating disk wirelessly via Bluetooth on smartphone using BTE-terminal apps. Details of these apps are in the assembly instructions (Vadaparty 2018a).

The Cirkinemeter allows students to perform many creative experiments on its rotating frame. A student can measure the radial position on its disk (r), the angular velocity (ω) using its photogate, and the radial acceleration (a_{radial}) at r using the accelerometer device, all independently. This data allows

students to quantitatively confirm/derive the familiar (Young, 2016) relationship for the magnitude of the radial acceleration:

$$|a_{radial}| = \omega^2 r.$$

In addition to the magnitude, the Cirkinemeter also confirms the direction of this acceleration, and thus the existence of radially outward centrifugal acceleration on rotating frames, clarifying to students whether the forces felt on a rotating disk are real or "fictitious". These topics are discussed in Sections 3 through 5. Finally, the Cirkinemeter enables students to generate quantitative polar graphs of the path taken by an object under the influence of Coriolis acceleration. These observed paths match with striking accuracy the theoretical predictions of Steyn-Ross and Ivey, as discussed in Sections 6 and 7.

The Cirkinemeter can reliably reproduce quantitative measurements of kinematics under Centrifugal and Coriolis forces[1]. We want students of the world to build their own Cirkinemeters and expand them for their own new experiments. To achieve this goal, all aspects of the Cirkinemeter are made available in the public domain (Vadaparty, 2018a): the build instructions, the code, the turn-table platform designs, and the 3D housings. A video (Vadaparty, 2018b) demonstrates the working and designs of the Cirkinemeter.

2. Anatomy of the Cirkinemeter

The Cirkinemeter runs on two DIY microcontroller boards, available at Adafruit Industries (Adafruit, 2017). The first one controls the speed and direction of the turn-table, and also displays the rotations per minute (RPM). The second microcontroller measures the instantaneous 3-dimensional accelerations from an accelerometer chip and transmits those accelerations to the user's smartphone through a Bluetooth device (HC-06). It is displayed on users' phones with BT terminal apps (see Figures 4(b) and 4(d)).

Figure 1 through Figure 4 show the full Cirkinemeter platform.

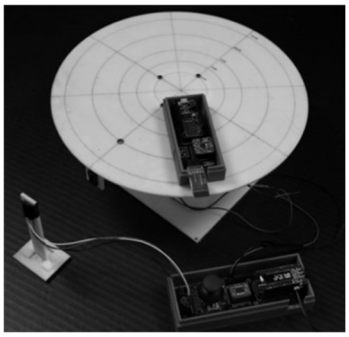


Figure 1 Complete Cirkinemeter Platform.

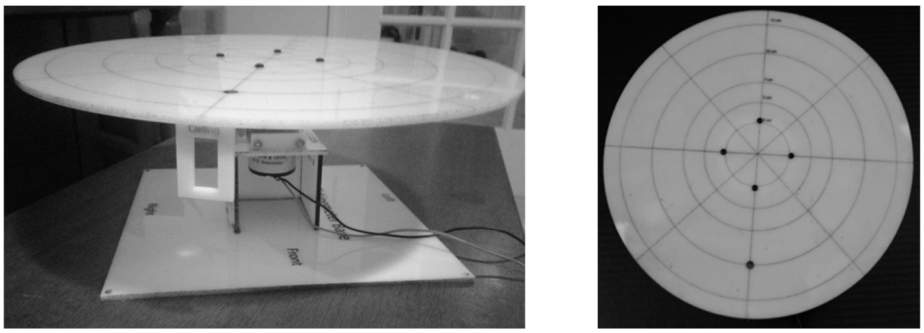
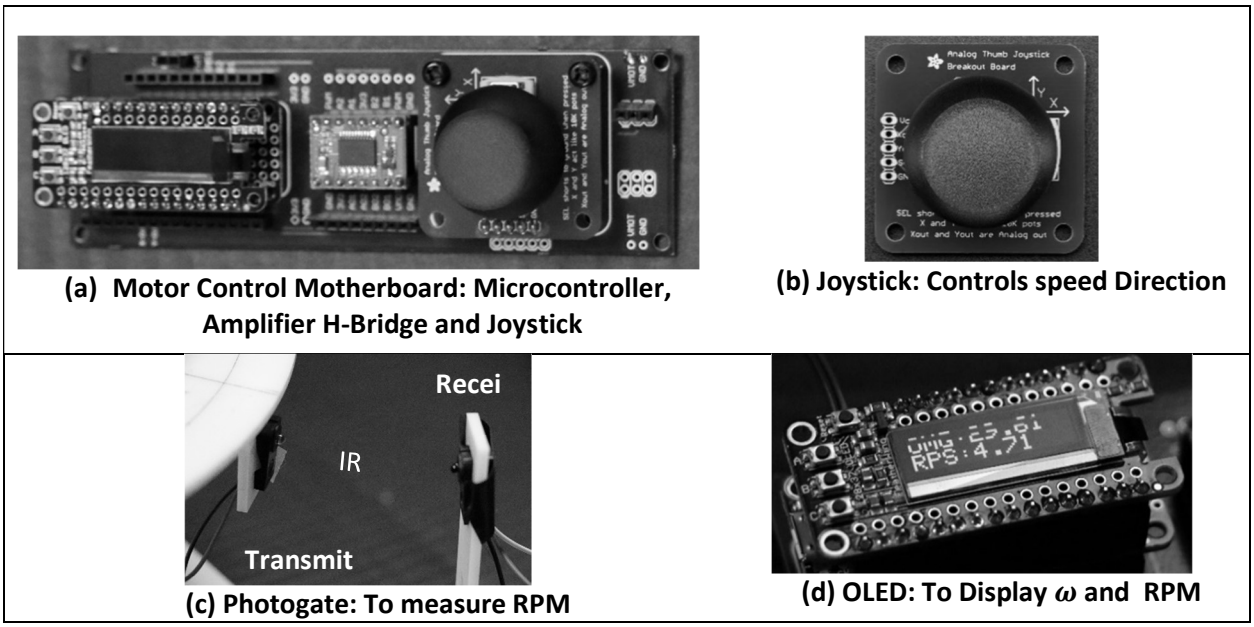


Figure 2. he laser cut turn-table housing: (a) front and (b) top view.

[1] In this paper where we use the term "force" we mean force/unit-mass unless otherwise stated.



(a) Motor Control Motherboard: Microcontroller, Amplifier H-Bridge and Joystick

(b) Joystick: Controls speed Direction

(c) Photogate: To measure RPM

(d) OLED: To Display ω and RPM

Figure 3. The motor-control mother board with its parts

Figure 1 shows the full Cirkinemeter in one view. Figure 2 shows the rotating turn-table top view and side view. It is on this table that we perform all experiments. For this device Rotating Frame = Rotating Disk. Figure 3. The motor-control mother board with its parts

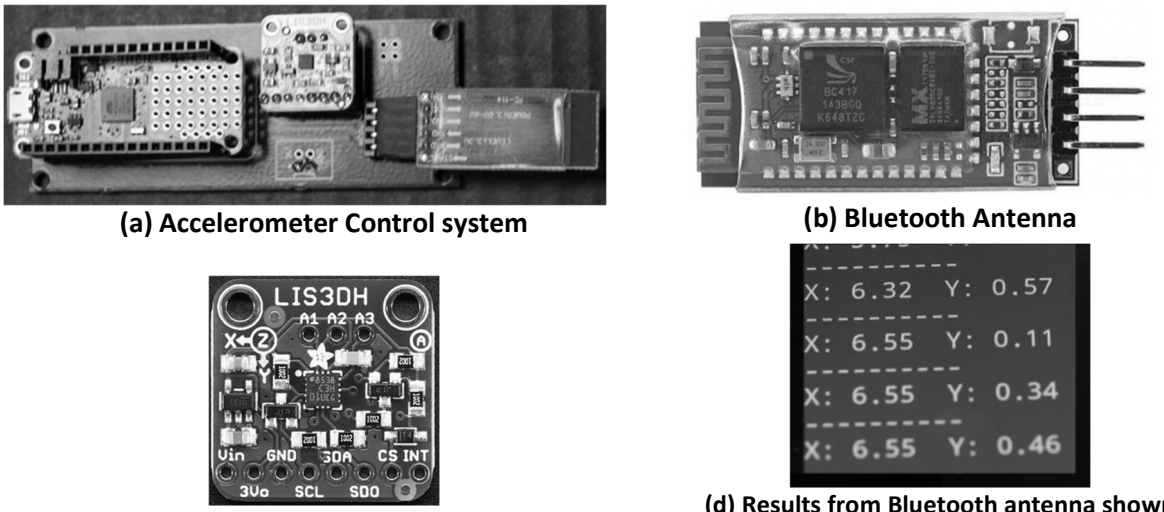
shows the electronic control system that we call the "mother board" with its parts. Figure 3. The motor-control mother board with its parts

(a) shows the full control system and Figure 3. The motor-control mother board with its parts

(b) shows the joystick that allows for control. Figure 3. The motor-control mother board with its parts

(c) shows the "Photogate" system with a transmitter (attached to the disk) and a stationary receiver. This system measures the RPM, by measuring every time the transmitter crosses the receiver. Figure 3. The motor-control mother board with its parts

(d) shows the display system consisting of an OLED, which shows the RPM and the angular velocity ω.



(a) Accelerometer Control system

(b) Bluetooth Antenna

(c) Accelerometer Chip

(d) Results from Bluetooth antenna shown on a smartphone

Figure 4. Accelerometer Control System and its parts

Figure 4 shows the accelerometer system and its parts. Figure 4 (a) shows the full system in one figure. It has 3 main parts: an Arduino based microcontroller (similar to the one we used earlier), an accelerometer chip, and a Bluetooth antenna. Figure 4 (d) shows the typical results received on a smartphone from the Bluetooth antenna.

3. Inertial and non-inertial frames of reference

In the scope of this paper, a reference frame (or, frame of reference) is the space defined with respect to three orthogonal axes (referred to as X, Y, and Z). A car moving due East at 60 mph is only moving with respect to the Earth frame of reference. If our frame of reference is the car, then the car is stationary, and the road is moving due West at 60 mph. A frame of reference can be anywhere: a stationary table, a rotating disk, a cannonball, etc. Once a frame of reference is established, an observer can then deduce the laws of kinematics (displacement, velocity, acceleration, etc.) of objects in that frame.

There are two kinds of reference frames: inertial and non-inertial. Any object in an inertial frame of reference follows Newton's law of Inertia: an object will remain at rest or move at a constant speed in a straight line unless it is acted upon by an unbalanced force. An example of an inertial frame is a frictionless table on which a marble rolls in a straight line.

Non-inertial frames, as their name suggests, do not follow Newton's law of inertia. For example, relative to the Cirkinemeter's rotating disk, a stationary spring balance attached at the center of the disk will measure a radially pulling outward force with no obvious source (electromagnetic, gravitational, etc.). In the Earth's inertial frame, on the other hand, an observer sees a radially inward force, known as Centripetal force, pulling the object to keep it in a circular path. From the disk's perspective, this radially inward force keeps the object stationary. Using the law of inertia, an observer on the disk (rotating frame) therefore concludes that there must be an outward force opposing the inward force, since the object is at rest on the rotating frame. This outward force is called the Centrifugal force. The magnitude of this radial acceleration a_{radial} at a given radial distance r is given by the familiar equation (Young, 2016)

$$|a_{radial}| = r\omega^2.$$

Because the centrifugal force is not observed in the inertial frame, it is sometimes referred to as "fictitious." For example, Khan Academy (Khan, 2016) ambiguously claims that the centrifugal force does not exist in a "good" reference frame. Even a standard text (see page 151 of (Young 2016)) actively forbids the term "centrifugal" force by saying it does not exist in inertial frames; they make no mention of non-inertial frames.

However, we agree with the authors Steyn-Ross and Ivey (see page 1074 of (Steyn-Ross, 1992)): "*We believe that the term 'fictitious' is a misleading one, and should be avoided. In the accelerated frame, such forces are real and measurable. The fact that they do not appear in an inertial frame does not make them imaginary, fictitious, or phony. The other common term, 'inertial forces,' seems to us to be more accurate and pedagogically helpful.*"

In summary, relative to an inertial frame, there are no "fictitious" forces like centrifugal force. However, relative to an accelerating frame (e.g., the Earth) the centrifugal force is real and measurable. For example, a person weighing 100 lb. at the poles will weigh 5.5 Oz less at the equator. This is because (i) the centrifugal force pulling away from the earth's gravity is the largest at the equator and is directly opposite to *g* and (ii) at the poles there is no centrifugal force on the person (poles are on the axis of rotation). See (NASA, 2015).

4. Determining the direction of the radial acceleration on a rotating frame

The Cirkinemeter enables students to perform many creative experiments. First, we explore radial acceleration on a rotating disk, and establish the existence of centrifugal acceleration on a rotating frame

of reference (i.e., radially outward acceleration). In order to determine if the radially outward Centrifugal acceleration exists, we need to know how the accelerometer measures the direction of a well-known acceleration. We do this by measuring the magnitude and direction of g, the gravitational acceleration on Earth towards its center.

When the device has its Z-axis pointing up, as seen in Figure 5, it measures approximately -9.8 m/s^2, confirming that the gravitational force is downwards (hence the negative sign). The same result occurs when the device is rotated such that X (or, Y) axis is pointed upward: the accelerometer measures -9.8 $/s^2$.

Figure 5. Shows how accelerometer is calibrated to gravity

Now that we know that the accelerometer measures the direction of a well-known acceleration correctly, we can apply this method on a rotating disk to see whether there truly is a Centrifugal (i.e., radially outward) acceleration on the rotating frame. First, we place the accelerometer on the rotating disk such that the X-axis of the accelerometer is pointed towards the center of the disk. See Figure 6.

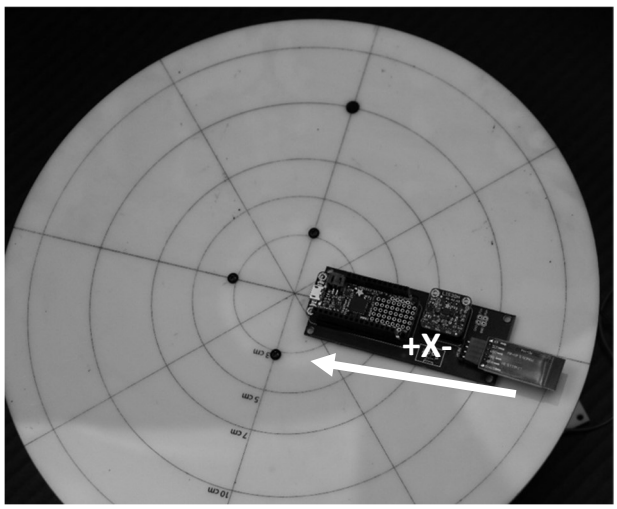


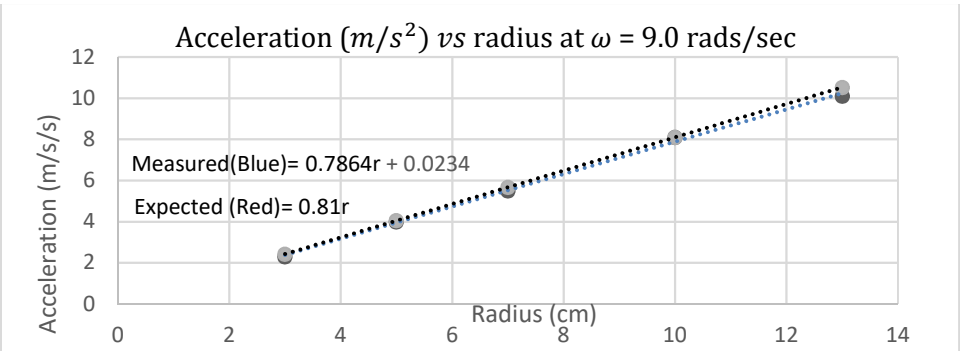
Figure 6 Shows how the accelerometer is oriented

When the Cirkinemeter's rotating disk starts moving, the accelerometer outputs negative values of acceleration along the X-axis. Based on our previous method of establishing reference using g, this means that there is a radially outward acceleration! The Centrifugal force is real on the non-inertial frame. The next series of experiments demonstrate how students can derive the relationship of the centrifugal acceleration, radial length, and angular velocity: $|a_{radial}| = \omega^2 r$.

5. Experiments to the Measuring Centrifugal Force

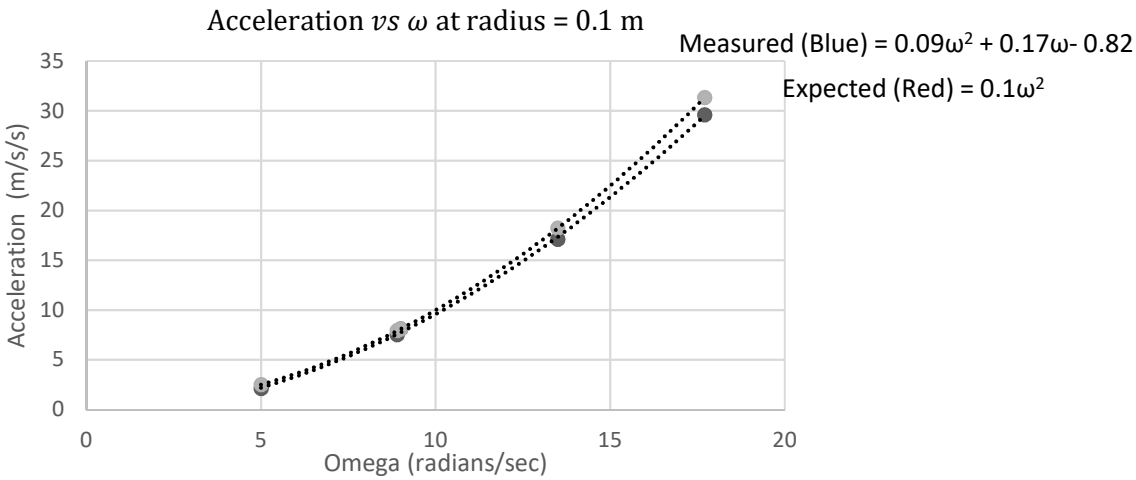
We describe two experiments, which together validate the formula: $|a_{radial}| = \omega^2 r$. First, we consider varying the radius while keeping the angular velocity, $\omega = 9\frac{rads}{s}$ as a constant. The expected relationship is $|a_{radial}| = \omega^2 r = 0.81r$, where r is measured in centimeters. The measured data (blue), as graphed below, almost exactly matches the expected line (red). The results are tabulated Table 1.

Table 1. Linear relationship between radial acceleration and the radius at a constant angular speed (ω) = 9.0 radians/sec



Next, we consider varying ω (angular speed), while keeping, $r = 10cm = 0.1m$ as constant. The expected relationship is $|a_{radial}| = \omega^2 r = 0.1\omega^2$. The measured (blue) data remarkably resembles the expected (red) graph. The results are shown in .

Table 2. Table 3 Quadratic relationship between radial acceleration and ω at a constant radius = 0.1m



6. Coriolis acceleration – Theoretical results

The most commonly used examples for the path followed by an object under the Coriolis force are hurricanes (not suitable for classroom experimentation). There are no commercially available high-school level instruments that can quantitatively measure the Coriolis acceleration. Luckily, in their 1992 paper (Steyn-Ross, 1992), Steyn-Ross and Ivey derived simple equations for the motion of a puck moving on a

frictionless rotating table when the puck is released along the diameter of the table. The authors also demonstrated that those paths taken by the puck can be reproduced using an oscilloscope to simulate the motion of the puck.

Fortunately, we can produce the paths demonstrated by Steyn-Ross and Ivey (Steny-Ross 1992) on the Cirkinemeter using a marker, and then compare those paths with their theoretical results, without an oscilloscope. It turns out that the results match with the equations with striking accuracy.

Steyn-Ross and Ivey derived (see page 1082 of (Steny-Ross 1992)) the expression for the path taken by an object under the Coriolis acceleration in a specific scenario. Consider a disk of diameter 2R at a constant (counter-clockwise) angular speed ω $\left(=\frac{2\pi}{T}\right)$, where T is the time period. If a marble rolls across the rotating disk's diameter with a constant inertial velocity $v_0 = \frac{4R}{T}$, then the marble's coordinates X(t) and Y(t) on the disk at a time t are given by the following parametric equations:

$$X(t) = r(t)\cos(\omega t), Y(t) = -r(t)\sin(\omega t) \qquad \text{... Equation (1)}$$

where $r(t)$ is the magnitude of the radial position at time *t.* r(t) is given by:

$$r(t) = \left(\frac{4Rt}{nT} - R\right) = R\left(\frac{4t}{nT} - 1\right) \qquad \text{... Equation (2)}$$

The term $\frac{4R}{T}$ represents v_0, the initial launch velocity, such that if the launcher on the disk throws at $\frac{4R}{T}$, he will catch it on the other side. n is a multiple used for fractions of $\frac{4R}{T}$ ($\frac{4R}{1T}, \frac{4R}{2T}$, etc.).

In the next two experiments, we verify the predictions of the 1992 paper with the Cirkinemeter. The radius is set to 13 cm and ω is set to $\pi\frac{rads}{s}$ (T=2 seconds).

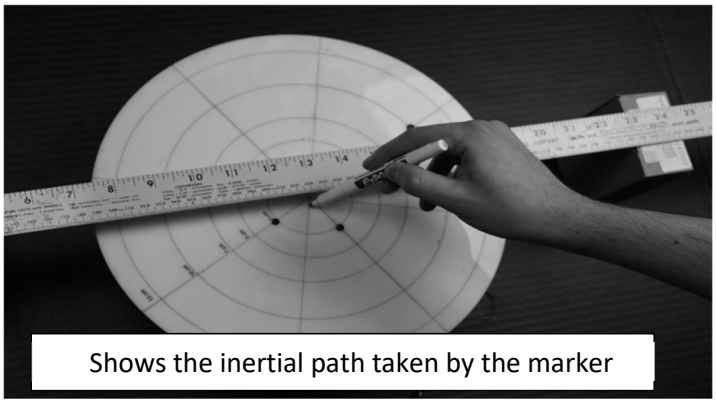


Figure 7 shows the Coriolis experiment setup

To simulate the motion of such a marble, we draw an erasable marker across the diameter at a constant velocity. The marker travels in a straight line (on the inertial frame). The ink left by the marker on the disk, however, follows the path made by the marble on the rotating frame. This set up is shown in Figure **7**.

7. Coriolis Experiments

In the first experiment, the marker covered the diameter in 1 second, which gives the expected radial magnitude of: $r(t) = 13(2t - 1)$ (n=1 and T=2 in Equation 2). The actual and expected polar graphs are shown in Figure 8. The parametric relationship (Equation 1) between X, Y and t is graphed using the graphing tool of Desmos.com. This tool is open source and freely available.

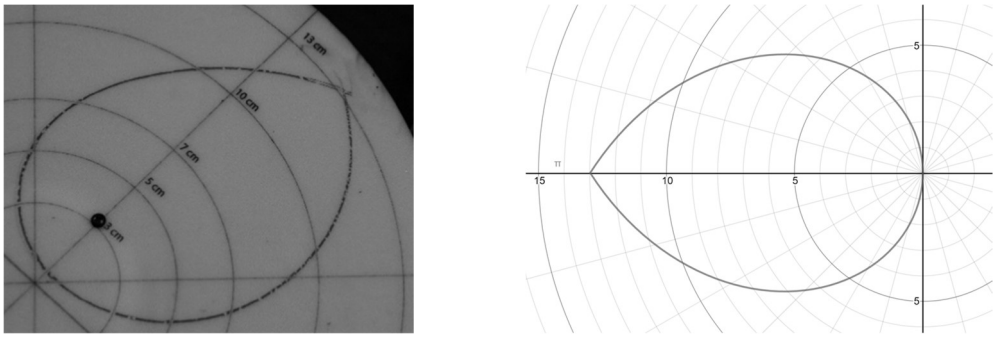


Figure 8. Coriolis graph when n=1 (a) the Cirkinemter's result (b) the predicted graph.

Next, the velocity is halved (n=2). The expected radius is $r(t) = 13(t - 1)$. The actual and expected graphs (using Desmos) are in Figure 8.

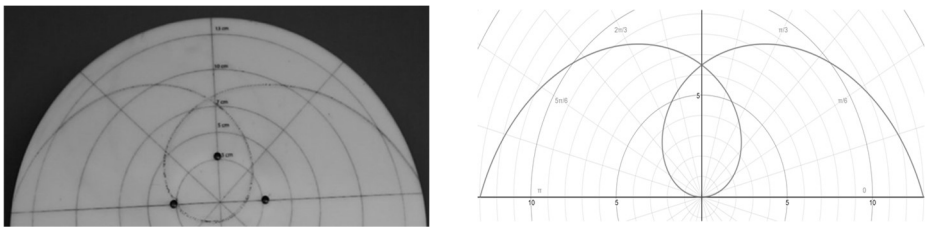


Figure 9. Coriolis graphs when speed is halved: (a) the Cirkinemter's result (b) predicted graph.

As can be seen from Figure 8 and Figure 9 the output of the Cirkinemeter match with striking accuracy the expected polar graph predicted by the theory (Steny-Ross 1992).

8. Comparison with Commercial K-12 Physics Labs Equipment

There are two large-scale companies, Pasco and Vernier, that sell instruments to perform experiments in K-12 education, and they do sell equipment for circular kinematics. In this section, we will analyze these instruments in various parameters: cost, experimental diversity, maintenance, and STEM academic benefits. We will compare these parameters to those of the Cirkinemeter.

8.1. Cost

Pasco sells an un-motorized, rotating platform, which costs about $430. In addition to this, Pasco needs the following accessories to perform Centripetal force experiments: a $100 Bluetooth wireless accelerometer sensor, a $45 photogate, a $70 "Digital Passport" to connect sensors to computers, and $35 "Centripetal Force Accessories". The total cost for the Pasco setup is $680. Pasco also offers a motorized platform that costs $675 for the base and an additional $999 for the stabilized power supply. This alternative will bring the price to $1,674.

Vernier sells its own un-motorized rotating platform at $450. Like Pasco, Vernier has its own wireless Bluetooth accelerometer sensor that costs $250. This brings the entire experimental setup to a cost of $700.

The Cirkinemeter's electronically motorized turntable costs just under $100, with all of the electronics and plastic housing included. The Bluetooth accelerometer device costs just under $40. This brings the total cost of the Cirkinemeter to approximately $140. Assuming a labor costs for assembly is added ($20 for 1 hour), the total cost of assembling all the parts of the Cirkinemeter will be about $160. This is about 10% to 20% of the competitors' costs, depending on the model.

8.2. Experiments

The instruments supplied by both Vernier and Pasco can measure the radial acceleration with respect to angular velocity. In order for students to perform this experiment on either company's setup, however, they need to spin the platform by hand. See the video on Vernier (Vernier 2018). This reduces the control students have over radial speed, impacting the ability to derive precisely the relationship we discussed: $|a_{radial}| = \omega^2 r$.

The Cirkinemeter enables students to plot radial acceleration against angular velocity just like the commercially available equipment. However, it has several advantages over Vernier and Pasco.

- The Cirkinemeter is motorized; this frees students to collect data consistently instead of spinning the wheel by hand.
- The Cirkinemeter's joystick allows students to control the rotating disk's angular speed and direction (clockwise vs counterclockwise) using a Joystick
- The Cirkinemeter can keep the speed steady at a specific value (we call it "auto-pilot").

In addition to performing the experiments available from Vernier and Pasco, the Cirkinemeter allows students to perform subtler experiments. For instance, the Cirkinemeter's accelerometer device allows students to confirm the existence and direction of the radially outward Centrifugal force. Additionally, the Cirkinemeter's large rotating disk allows students to plot quantitative graphs of objects influenced by the Coriolis force and compare those paths with those predicted by the theory[2]. Neither Pasco nor Vernier has accessories that allow students to observe or quantify the Coriolis force.

Furthermore, whereas Pasco and Vernier require custom software requiring licensing, the Cirkinemeter uses the Arduino IDE that is open for millions of students; its costs zero dollars.

8.3. Maintenance

Maintenance and support are crucial for any equipment. With the equipment bought from Pasco and Vernier, any break-down requires us to reach the vendor, and buy their parts (which are very expensive). There is no information available for users to build their own replacement parts.

The Cirkinemeter fixes this issue by using already open-source parts, such as the Arduino Feather, and by publishing instructions on how to assemble the equipment (Vadaparty 2018a). If a certain part of the Cirkinemeter malfunctions, students can easily find and order that inexpensive part from the manufacturers (Vadaparty 2018a).

8.4. STEM Education

Several engineering colleges and universities have Maker Spaces and encourage their students to be "hands on" in engineering. As mentioned in Section 8.3, Vernier and Pasco are not open-sourced. Therefore, students have no knowledge on how the equipment works nor how to design similar physics equipment. However, every aspect of the Cirkinemeter, from the plastic turntable to the Arduino-based electronics, is made so that students not only learn physics but also learn key STEM manufacturing and rapid prototyping skills. This open source availability of the Cirkinemeter design motivates students to learn modern digital manufacturing skills: laser-cutting, programming and 3D-printing.

9. Closing Thoughts

The Cirkinemeter can perform several experiments related to the Centrifugal acceleration and the Coriolis acceleration on the rotating frame (turn-table), enabling students to internalize kinematics on rotating frames of reference. Because all aspects of the Cirkinemeter are public and are completely

customizable, students can modify the platform to measure many more characteristics of kinematics on rotating frames, such as the following:

- Students can pursue the theory and verification of motion along non-diametric paths. These will test their deeper understanding of the physics behind motion in the circular frame of reference.
- Students can experiment with continuously changing angular velocity.

We hope that many students would benefit from experimenting on the Cirkinemeter both for deeper understanding of Physics through hands-on experimentation and better engineering abilities that enable building better equipment. By building the Cirkinemeter from scratch, students get a firsthand introduction to basic electronics and Arduino coding. Additionally, by providing students ways to collect lots of distinct data (acceleration, radius, omega, and polar graphs), students do not just derive the relationships of kinematics but also retain the method used to test and conclude such relationships. Ultimately, the Cirkinemeter's purpose is to teach students how to *learn*. The confidence and experience they gain will allow them to enter fields that were previously inaccessible. Ultimately, we want to use disruptive technology to break the technological and financial barriers for STEM education.

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