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PROCEEDINGS

OF THE  
INTERNATIONAL  
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SYSTEMS



# INDUSTRY, ENGINEERING & MANAGEMENT SYSTEMS CONFERENCE

March 15-17, 2020

Dear Conference Participants:

It is with pleasure that we present to you the Proceedings of the 2020 International Conference on Industry, Engineering and Management Systems (IEMS). The papers presented this year consistently represented high quality scholarship in the authors' respective fields. The papers covered a wide range of topics in the business and engineering disciplines, integrating concepts that further the mission of the IEMS Conference.

We present these Proceedings to you to enable your own thought leadership so that you may share your presentations and papers in the future at our IEMS conference.

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 special thanks to our Associate Editor, Lauren Schumacher, for helping to make these publications a success.

We look forward to seeing you virtually at IEMS 2021!

Warm Regards,

Ron Barrett-Gonzalez, Ph.D.  
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## Industry Capstone Projects as a Vehicle for Faculty Development

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**Abstract:** There is a trend in Engineering education pedagogy focus from problem-based learning to project-based learning. An impediment to this shift in Engineering Education lies in faculty preparation. Strategies to help faculty develop skills while they are working is essential to providing project-based learning activities within engineering programs. Interviews conducted suggest that senior projects are a valuable steppingstone for faculty that initially have no real-world experience in engineering or manufacturing. Allowing faculty to participate in these projects allow them to create industrial contacts and see the skill sets their graduates will be using. The projects provide faculty credibility to the students because they are working with them to solve a common problem. Finally, the paper provides best practices in the senior project program as well as the roles and responsibilities of the faculty, students, and industrial partners that participate in it.

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### 1. INTRODUCTION

Trends in Engineering education pedagogy focus on increasing the application of skills in a move away from problem-based learning to project-based learning. Reasons for this shift center around engaging students in higher order learning activities to address retention, persistence, and completion of Engineering and Technology programs. (Chandrasekaran, 2012). A barrier to this fundamental shift in Engineering Education lies in the faculty preparation. Because engineering education has little focus on skills development (Dewey, John. 1963) Many Engineering educators are woefully underprepared to implement project-based learning in their curriculum (Aglan, H.A. 1996). This, coupled with declining numbers of vocational education faculty, creates an environment where the necessary skills and knowledge needed to maintain a project-based learning curriculum do not exist within most Engineering or Technology programs (Besterfield-Sacre 2014, Hartman, B.A 2000). There are strategies to help faculty develop skills while they are working. This paper examines the impact of mentoring senior industrial capstone projects on engineering technology faculty. The research uses a qualitative case study approach where faculty are interviewed to determine their existing comfort and skills managing projects.

The Tarleton State University Engineering Technology program has been conducting an industrial-based senior project program for over 20 years, utilizing program faculty as project mentors. While the impacts the projects have on students are well-documented, impact on faculty is less understood. A continual and planned interaction between industrial partners and students might have an impact on faculty members, particularly those with limited industrial experience. Providing this experience could have a multidimensional impact on faculty through working with students on a project-based assignment, interacting with industry and experiencing how they go about solving problems, modeling professional behavior with other people on the team, and seeing how content that they teach is applied in the real world. Having these experiences might have impact on their teaching and how they teach their classes.

To investigate this, the study used a qualitative case study methodology (Creswell 2014). The population of the study was the faculty of the engineering technology department. A qualitative semi-structured interview guide was developed (Turner 2010) with questions focused on using a faculty's teaching history,

industrial history, managing industrial projects, and the comfort level of faculty managing students in projects. The framework for questions consisted of eight questions grouped into the previous four categories:

1. Teaching
  - a. Describe your teaching experience.
  - b. What key takeaways do you have from the mentoring experience? Have you used anything gained in subsequent teaching?
2. Industrial Experience
  - a. Please describe any work experience you have in industry; how long, type of industry, full-time, etc.
  - b. Describe some of the projects you were involved in. Which were most rewarding and which may have been least rewarding?
3. Managing Industrial Projects
  - a. Describe any experience you have in managing projects of any kind?
  - b. Do you think mentoring these projects has helped you individually or professionally? How so?
4. Managing Students in Projects
  - a. Describe your comfort level in working with students and industry participants on projects
  - b. What might you do differently when mentoring your next group of students?

There were 10 faculty who qualified for directed interviews. Comfort level managing student industrial projects was reported based on the responses on each of the interview categories. Table 1 provides summary information about the respondents. Pseudonyms were used in place of actual names of participating faculty members (Creswell, 2014).

**Table 1. Participant Coding Sheet**

<b>Table 1 Participant coding sheet Topics:</b>	<b>Dr. Smith</b>	<b>Dr. Rice</b>	<b>Mr. Prince</b>	<b>Dr. Mora</b>	<b>Mr. Sanchez</b>	<b>Ms. Wheeler</b>	<b>Mr. Griffith</b>	<b>Dr. Moses</b>	<b>Dr. Barry</b>	<b>Mr. Cameron</b>
Teaching experience (years)	7	5	6	21	20	5	2+	2	1	11
Industry experience (years)	10	40	30	1	2	10	12	3	0	2
Project experience (number of)	10+	30+	10+	30+	2	5+	0	2	1	6
Comfort level with students and industry	Industry High - Students, not quite so high	Industry High - Students, not quite so high	High	Industry High - Students, not quite so high	High industry low	High	High	Industry High - Students, not quite so high	High	High with students medium with industry
No. of sr. projects involved in	15	4	15	20	7	3	5	2	1	7

## 2. DISCUSSION OF THE FINDINGS

### 2.1. Teaching experience

The more teaching experience the subjects had, the more they valued project-based learning. Faculty members Smith, Rice, Prince, Sanchez, and Wheeler all highly valued the project-based learning activities in their own classes and in mentoring the senior project classes. This tracks with the interview language that indicated the more comfortable the faculty was teaching the groups in applied projects, the more likely they would be in using that type of instruction in classes. Faculty such as Drs. Ortiz, Moses, and Barry, while supportive of the senior project classes, indicated that they would be less likely to use project-based education in the classes they teach. However, faculty that are not using project-based education within their classes indicated that they were using the experiences they gained in the senior project mentoring experience to provide examples of application to undergraduate students that are in their classes.

### 2.2. Previous industrial experience

Not surprisingly, faculty that had more industrial experience were more comfortable mentoring the senior projects and were more likely to use project-based learning in their classroom. These faculty (Drs. Smith, Rice, Mora, and Mr. Prince) had over 10 years of industrial experience and indicated that they were very confident in mentoring the student projects. While the older and more experienced faculty indicated that they were comfortable teaching the senior projects, faculty with less industrial experiences expressed several different activities. Dr. Barry indicated he used the project class to model behavior of how engineers should interact with a client. Dr Barry talked about listening skills and explaining engineering phenomena to the customer because the customers may not be trained in the discipline that they are asking them to perform. When asked if he planned to focus on this, Dr. Barry indicated that initially he did not. However, the types of projects he was managing required a lot of calculations and explanations to the customers.

Some common experiences were found in talking about the least favorite industrial project experience, which focused on situations where the company changes the scope of the project unexpectedly. For faculty with an industrial history, this was less stressful, but faculty with less industrial experience viewed the change with a great deal of stress. When we examined why this was stressful, the faculty members with less industrial experience tended to treat the senior project students as an independent group who they were providing advice to. Faculty with more industrial experience treated the group like employees they were responsible for and this resulted in more deliberative approaches when the scope of the project changed. That is, inexperienced mentors perhaps fretted over changes and hoped for the best from students while experienced mentors provided more direct guidance. Dr. Rice indicated, “You have to plan that the customer is going to change their minds. That’s just how customers are.”

### 2.3. Managing industrial projects

Once again, the prime indicator here was industrial experience. Faculty with the most work experience indicated they felt their role was to act as a resource and tell their group when they were not going to be successful. Faculty with less industrial experience tended to be more active within the team providing specific tactics to solve problems. Faculty with more industrial experience tended to ask questions and challenged assumptions to provide feedback to students or help the team work through problems.

There was a distinction in faculty with less industrial experience in that they were more likely to change what they were teaching in their classes. When faculty with more industrial experience were asked if they were ever challenged to change what they were teaching based on what they observed in a senior project, the answer was yes, but they felt they were already aligned.

### 2.4. Managing students’ industrial projects

Previous sections have already indicated that faculty with more industrial experience were more

comfortable mentoring senior projects. In this question, there seems to be a consensus among all the faculty that having a more detailed plan for projects up front is desirable. Faculty with more industrial experience tended to be less tolerant about slippage in time for the projects and were unwilling to move forward until there was a solid plan in place. There was a difference between faculty in redirecting students' behavior. Dr. Ortiz indicated that she tells her students what they should do in their proposal, but if they don't do it, she will reflect that in their final grade.

### 3. CONCLUSIONS

Experience is the key, not only in mentoring senior projects, but also in doing project-based learning in a college classroom. However, for faculty without industrial experience, they seem to value the experience of working with outside companies. The interviews would suggest that senior projects are a valuable steppingstone for faculty that initially have no real-world experience in engineering or manufacturing. Allowing faculty to participate in these projects allow them to create industrial contacts to see what skill sets their graduates will be using. The projects provide faculty credibility to the students because they are working with them to solve a common problem. Finally, inexperienced faculty become more at ease working in a team-based project using application-based, project-based learning.

### 4. FUTURE RESEARCH

Future research on this topic could include the impact of project-based learning on student retention and persistence. Additionally, there is argument that because project based learning focuses on higher levels of learning on the application levels and above that this student center focus will provide a deeper level of learning and thus a more prepared student. Without assessment evidence of this it will remain speculation. Finally, because we know that project-based learning is time and resource intensive it would be useful to look at barriers of implementing and sustaining project based education in universities.

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## Quality in eLearning: Perceptions of Instructors

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**Abstract:** eLearning is rapidly growing and competing with traditional classroom learning. Advancements in digital technology and democratization of the internet have made eLearning more accessible, flexible, and convenient way for acquiring knowledge. This study examines the instructors' perceptions of quality in eLearning in higher education in the United States. Content analysis of 119 peer-reviewed articles published from January 1997 to January 2020 was performed. The Results revealed the most important dimensions of quality from the viewpoint of instructors. The steps involved in identifying these dimensions and determining their relative importance are represented. Utilizing factor analysis, four uncorrelated meta-dimensions were extracted. The paper concludes with practical implications and proposes directions for future research.

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### 1. INTRODUCTION

The use of computers and other digital technologies in education has grown and expanded in recent decades, and for many real-world activities, eLearning is becoming important. The exponential growth in Information and Communication Technology has transformed the processes of teaching and has helped improve the learning process. eLearning has targeted a large audience of students with limited time or resources, located in areas of conflict and post-conflict, have limited mobility, or facing communication difficulties.

Academic officials in the United States have suggested that online learning is critical to their institutions' long-term growth, indicating that there is greater demand for online courses or services than for face-to-face courses. Online education now means that in order to fulfill a course or even a degree, applicants no longer need to be willing to meet face to face [Jaggars and Bailey (2010)].

Quality has always been a major concern in digital education in general. According to Williams and Jacobs (2004), the quality framework particularly for eLearning could be a critical factor for progress. In fact, eLearning program quality cannot be conveyed and set by a simple definition without recognizing the details as the word quality is a very abstract notion which carries different dimensions such as quality of service, quality of information, and quality of systems. As was pointed out by Parasuraman (1985), differences in perceptions between administrators' and instructors' result in one of the four gaps associated with the quality of design, marketing, and delivery of services.

This research attempts to identify instructors' perceptions of quality in eLearning by examining a sample of peer-reviewed journal articles. The following section presents a review of the literature. This is followed by a presentation of the data collected and the statistical analysis performed. Results and conclusions with directions for future research are presented in the last section.

## 2. LITERATURE REVIEW

eLearning, also known as distance, online, or digital learning refers to a system of imparting knowledge through teaching from a distance where technology is used. As was pointed out by Warschauer (1997), in these cases, the student is physically absent from the classroom but through technology, virtually interacts with the instructors and tutors. Cook, Crawford, and Warner (2009) indicated that eLearning provides access to education in situations where time, distance, or both separate the source of information (instructors) and the recipient (students).

The widespread acceptance and rapid growth of eLearning programs in higher education have been evident over the last decade. A significant proportion of higher education institutions have moved from offering individual online courses to providing complete online programs. Two recent studies monitoring the growth of online education in the U.S. show that while the enrollment rate in the face to face classes is trending down, online education enrolments are on the rise, with one in three students in the U.S. higher education sector taking at least one online course [Seaman, Allen and Seaman (2018), Legon, Garett, and Fredericksen (2019)].

According to Alhabeeb and Rowley (2018), eLearning systems offer opportunities for teaching and play a vital role in promoting new teaching methods. Zare et al., (2016) indicated that eLearning is a state-of-the-art tactic in learning and teaching via electronic information contexts aimed at increasing the quality of learning and teaching. Also, Unwin (2008) pointed out that eLearning offers a higher ability to resource sharing, cost-effectiveness, and flexibility. It also helps to monitor the progress of the students and motivate them by combining family life and learning.

Numerous researches cited the importance of faculty support of, and participation in, eLearning to the future growth of online education. These include research by Davis (2009), Green et al., (2009), Moloney and Oakley (2010), and Wasilik and Bolliger (2009). For example, Orr et al. (2009) conducted a qualitative study of faculty and administrators and found that faculty motivation is critical to the success of institutional efforts to expand online education. Green et al., (2009) pointed out that higher education institutions need to have programs in place to address the turnover rates of online instructors for their online programs to be successful. Similarly, Wasilik and Bolliger (2009) suggested that faculty satisfaction is an important factor influencing the overall success of online education programs.

Shaik, Lowe, and Pinegar (2006) identified two quality dimensions of online distance learning programs, namely, administrative and instructional services. The instructional services relate to the instructor's educational interactions and data on the university's education portal. Whereas the administrative services mainly apply to support desk programs, consultants, administrative staff, and school administrators.

Lin (2007) used an information systems model to identify success factors for eLearning programs. He identified three factors, namely system quality, quality of information, and quality of service. Schibrowsky and Drago (2007) suggested that six factors can be used to measure the quality of education. The interactions between students and students, the interactions between teachers and students, the quality of teaching, the content of courses, the structure of courses, and support and mentoring for teachers. They indicated that the quality of teaching is the most important factor followed by the frequency of interactions between teachers and students.

Al Awadh and Weheba (2020) conducted a study to determine perceptions of quality in eLearning from the perspective of top administrators. The research utilized a sample of public statements made by program administrators from the 100 top-ranked universities offering eLearning programs in the U.S. They applied the same coding scheme that was developed and validated by Alotaibi et al (2016). The scheme was used to perform textual analysis and determine the frequency of occurrence of each dimension and its codes. They concluded that perceptions of top administrators are dominated by experience properties. Based on factor analysis, they identified two meta-dimensions used by the administrators to describe the quality of their respective programs, namely, engagement and trust.

**Table 1. Initial dimensions and their definitions**

<b>Dimension</b>	<b>Definition</b>
Reliability	Consistency of performance and dependability; means performing the service right the first time and that the institution honors its promises.
Responsiveness	Willingness and readiness of faculty and staff to provide service.
Competence	Possession of required skills and knowledge to perform the service.
Access	Approachability and ease of contact.
Courtesy	Politeness, respect, consideration, and friendliness of contact person.
Communication	Keeping stakeholders informed and listening to them
Credibility	Trustworthiness, believability, and honesty
Security	Freedom from danger, risk, or doubt
Understanding	Making an effort to understand stakeholders' needs
Performance	Primary operating functions of the institution
Conformance	The extent to which the institution meets pre-established standards (both internal and external).
Features	Supplemental characteristics offered by the institution.
Tangibles	Physical evidence of service.

Source: Adapted from Alotaibi et al. (2016)

### 3. RESEARCH METHODOLOGY

Computer-Aided Text Analysis (CATA) refers to the use of computer applications to analyze wording used in surveys and publications. It is useful for coding, analyzing, and interpreting a text. This type of analysis allows researchers to take advantage of automated processes in making guided conclusions based on the textual contents of publications. It also saves time and improves accuracy. In this paper, the procedures recommended by Short et al., (2010) for conducting CATA were followed. These procedures can be applied to a large set of data and still maintain high reliability [Duriau et al., (2007)].

In this research, database search for publications was performed using Google Scholar and WSU Smart Search. The search was restricted to journal articles published between January 1997 and January 2020. As shown in Figure 1, initially publications with titles containing the word “quality” combined with the words “eLearning education,” “online education,” “distance education,” “blended education” resulted in 3992 publications. These were further reduced to 279 papers by restricting the search to peer-reviewed articles in the English language and text in a searchable pdf file format. Abstracts of these publications were screened and the papers were classified into two groups. One group included papers representing the views of instructors (teachers or professors), the second group included papers representing the views of students (e-learners). The objective of our research was focused on papers identified in the first group only and included 119 papers. These were considered units of analysis for the CATA.

The research methodology followed closely follows that described by Al Awadh et al., (2020). Initial dimensions (constructs) with their definitions, shown in Table 1, were used except for *tangibles*. This dimension was omitted as it represents physical aspects such as laboratories, classrooms, and libraries. These are not relevant to eLearning programs. The research adopted the coding scheme shown in Appendix A for the remaining 12 dimensions. The full manuscripts of the selected publications were analyzed using

the NVivo Version 10 (QSR International 2016). Each publication (unit of analysis) was imported into the software to determine the frequency of occurrence of each dimension and its codes.

#### 4. ANALYSIS AND RESULTS

The textual analysis resulted in 23,256 occurrences for all 12 dimensions and their codes. The results are depicted in the Pareto chart shown in Figure 2. Assuming that the frequency of occurrence reflects the importance of each dimension, it appears that *communication*, *performance*, *features*, *competence*, *reliability*, *responsiveness*, and *understanding* appear to be the most important dimensions used. These seven dimensions account for 85 % of the total count. *Communication* is the dimension used the most by instructors (23%), followed by the *performance* (20%). These two dimensions are used to describe the operating functions offered by the institution. On the other hand, conformance, credibility, security, and courtesy contributed less than 15 % of the total count. These appear to have much lower importance from the instructors' point of view. Both conformance and credibility contributed about 7% each to the total count. Whereas security and courtesy were the least observed dimensions, contributing only 2% of the total.

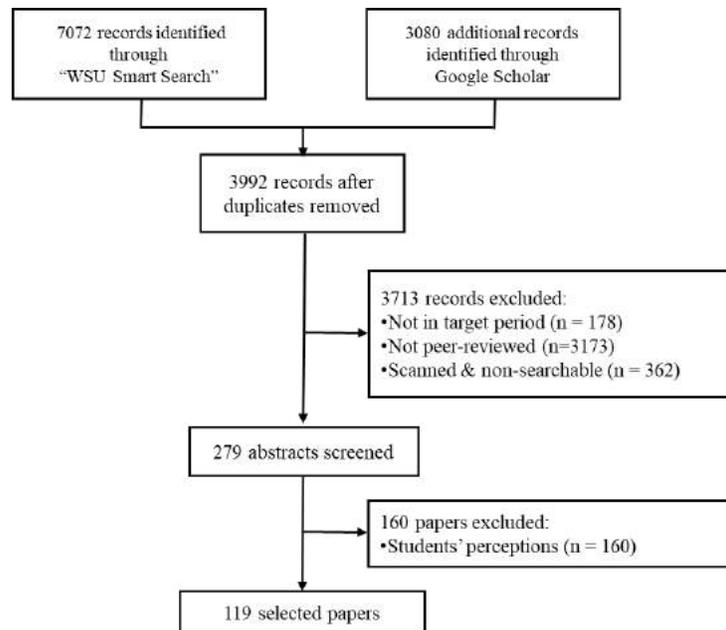


Figure 1. The PRISMA flowchart for publication selection

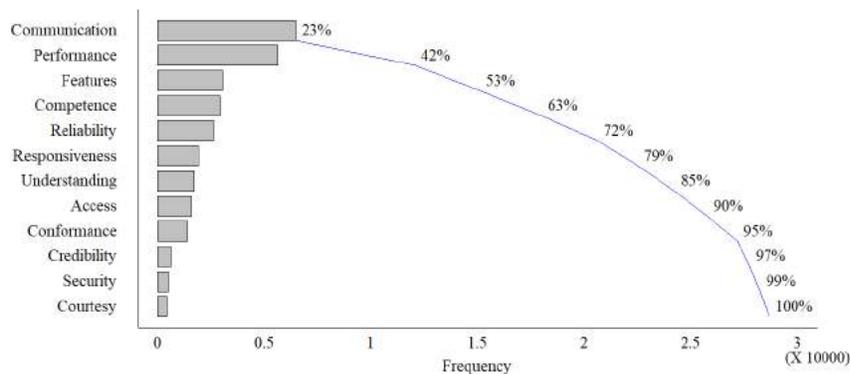


Figure 2: Pareto chart based on textual analysis

Factor analysis (FA) was applied in an attempt to reduce the dimensionality of the data into a smaller number of uncorrelated factors (meta-dimensions). FA uses the frequencies obtained from textual analysis to identify strong patterns in the data and possibly decrease the total number of dimensions (Brown, T. A., 2015). The frequency data were used to construct a 119 X 12 matrix that was used for the factor analysis. The rows represented the publications and the columns accounted for the dimensions. Cells of the matrix contained the frequency of occurrence of each dimension within a given publication. The analysis was performed using the Statgraphics Version 18 (Statpoint Technologies 2020). A Factorability test was performed to determine if some common factors can be extracted. The Kaiser-Meyer-Olson (KMO) test utilizes a statistic that measures how efficiently FA can reduce the dimensionality of a data set. It compares the magnitudes of the correlation amongst the variables to the magnitude of the partial correlations, determining how much common variance exists amongst the variables. According to Johnson and Wichern (2002) for the analysis to be useful, KMO should be greater than or equal to 0.6. In our data, the test resulted in a value of 0.76 suggesting that FA should be able to efficiently extract common factors. The results of the FA are shown in Table 2.

**Table 2: Results of Factor Analysis**

<i>Factor Number</i>	<i>Eigenvalue</i>	<i>Percent of Variance</i>	<i>Cumulative Percentage</i>
1	<b>3.59837</b>	29.986	29.986
2	<b>1.3229</b>	11.024	41.011
3	<b>1.20367</b>	10.031	51.041
4	<b>1.0309</b>	8.591	<b>59.632</b>
5	0.825679	6.881	66.513
6	0.789081	6.576	73.088
7	0.73795	6.150	79.238
8	0.64908	5.409	84.647
9	0.597289	4.977	89.624
10	0.572938	4.774	94.399
11	0.390028	3.250	97.649
12	0.282113	2.351	100.000

The Kaiser-Guttman rule was used as the stopping criterion in factor analysis [Kaiser (1960)]. The criterion requires that factors linked to eigenvalues greater than 1.0 are considered nontrivial. As shown in Table 2, four uncorrelated factors can be extracted. These four factors account for about 60% of the total variability in the data.

Table 3 illustrates the eigenvector coefficient (weight) of each of the 12 dimensions relative to each factor. As pointed out by Dunteman (1989), a positive value of weight indicates a positive correlation between the dimension and the factor. Similarly, negative values indicate negative correlations. Dimensions with absolute values of the eigenvector coefficients greater than 0.25 are considered as major contributors to each factor. Results indicated that *competence*, *communication*, and *understanding* made significant contributions to the first factor (F1). *Communication* had the highest frequency in the publications accounting for 23% of the total count. Whereas, *responsiveness*, *access*, and *reliability* made significant contributions to the second factor (F2). Both *courtesy* and *credibility* contributed to the third factor (F3). *Security*, *features*, *conformance*, and *performance* made significant contributions to the fourth factor (F4). These results are summarized in Table 4.

**Table 3: Factor Score Coefficients**

Dimensions	F 1	F 2	F 3	F 4
Reliability	0.47068	<b>0.581138</b>	0.279166	0.159954
Communication	<b>0.650759</b>	0.20888	0.0438067	-0.0242288
Performance	0.233967	0.47644	0.243263	<b>0.499079</b>
Understanding	<b>0.636415</b>	0.080191	0.243206	0.0902959
Access	0.0476949	<b>0.608613</b>	0.154799	0.191275
Courtesy	0.00350684	0.130985	<b>0.886796</b>	-0.0277119
Responsiveness	0.109784	<b>0.857348</b>	0.0198162	-0.114527
Conformance	0.471142	-0.0224799	-0.0355626	<b>0.526213</b>
Security	-0.364903	0.112007	0.00226512	<b>0.723873</b>
Credibility	0.242296	0.168917	<b>0.810159</b>	0.145519
Competence	<b>0.719279</b>	0.0996312	0.0259568	0.0675944
Features	0.392532	0.043766	0.102888	<b>0.567689</b>

**Table 4: Instructors' perceptions of quality in eLearning**

F1	F2	F3	F4
Competence	Responsiveness	Courtesy	Security
Communication	Access	Credibility	Features
Understanding	Reliability		Conformance
			Performance

## 5. DISCUSSION AND VERIFICATION

The results in Table 4 indicate that the first factor includes *competence*, *communication*, and *understanding*. These dimensions relate to the instructor’s knowledge and ability to develop a close and harmonious relationship (rapport) with his students. It contributes 30% of the total variability and appears to be the factor driving instructors’ perceptions. This factor was identified as a key element in engaging students as was noted by Kulenschmidt (2010), Smidt, et al., (2017), and Al Awadh and Weheba (2020).

The second factor includes *responsiveness*, *access*, and *reliability*. Within the sample of publications analyzed, these dimensions appear to focus on the characteristics of the system used to deliver content. This factor contributes 11% of the total variability and relates to the technology infrastructure. It refers to the system’s ability to support eLearning easily and dependably. It also refers to the ability of the supporting staff to manage the system and help its users. This factor was identified as “*technology*” by Alaneme, Olayiwola, and Reju (2010), Bokhari and Ahmad (2011), and Paul and Cochran (2013). Also, Burnette (2015) referred to this factor as the infrastructure, resources, and systems required for delivering instructions.

Both *Courtesy* and *credibility* contribute to the third factor, which accounts for about 10% of the total variability. This factor considers aspects related to the interactions between instructors, students, and the supporting staff. Instructors appear to value friendly and honest interactions. A similar finding was reported by Anderson (2004), Selim (2007), and Balaji and Chakrabarti (2010).

The fourth factor includes *security*, *features*, *conformance*, and *performance*, which account for 9 % of the total variability. These dimensions pertain to institutional standards and the procedures used in achieving them. Within the context of eLearning, this factor appears to encompass all institutional functions required to support eLearning activities. The significance of this factor was noted by Ehlers (2004) and Yang and Liu (2007).

## 6. CONCLUSIONS

This research examined the instructor's perceptions of quality in eLearning based on published research. To assure reporting quality, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed in selecting a sample of 119 papers. The search was limited to papers published between January 1997 and January 2020. Based on the textual analysis of the full contents of these papers, the frequency of occurrence of each the 12 dimensions and their codes revealed that *communication, performance, features, competence, and reliability* are the top five dimensions used by the instructors to describe quality in eLearning. These dimensions have a relatively high frequency of occurrence in the sample reflecting their importance in scholarly research.

Factor analysis suggested that the 12 dimensions could be reduced to four factors or meta-dimensions. These may be referred to as *aptitude, infrastructure, friendliness, and operational procedures*. *Aptitude* appears to be the most influential factor as it relates to the knowledge and skills of the instructors. Institutions with some input from instructors typically establish both the infrastructure and operational procedures. The effect of instructors depends to a large degree on the level of their participation in establishing institutional policies and funding priorities. Instructors view friendly interactions as the key to a productive and engaging relationship with students and staff. While these four factors are not claimed to be comprehensive, they represent a starting point for understanding instructors' perceptions of quality. Indeed, a different sample of articles may produce different results. Nevertheless, the research reflects views of what researchers considered as dimensions of quality. While it may be difficult to justify using the perspective of a single expert, this research provides means to consolidate views of instructors from different fields. In this context, the research findings offer a platform for measuring the level of satisfaction of instructors. Such measures would enable institutions to identify opportunities for improvement and allocate funds accordingly.

It is important to note here that following the conclusion of this research, the COVID-19 pandemic was confirmed to have reached the U.S. Almost all educational institutions had to make the abrupt switch to digital learning. Higher education institutions had to depend on eLearning to mitigate serious economic and social consequences of school closures. Online education and eLearning are no longer alternatives to face to face classes. As of March 2020, online education became the only acceptable solution. These authors expect to identify more publications on this topic as the number of instructors engaged in eLearning increases and perceptions change. Future research efforts would help demonstrate the longitudinal validity of the proposed factors and identify changes in perceptions.

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**Appendix (A)**

**List of Codes**

<b>Construct</b>	<b>Code</b>	<b>Construct</b>	<b>Code</b>
Reliability	Accuracy Completeness Confidence Consistency Stability	Security	Assurance Confidentiality Protection Safeguard Safety
Responsiveness	Flexibility Diversity Readiness Willingness Preparedness	Understanding	Accept Assist Appreciate Cooperate Recognize
Competence	Capability Experience Knowledge Skill Qualification	Performance	Developing Evaluating Improving Measuring Training
Access	Advising Affordability Approachability Availability Capacity	Conformance	Accredit Achieve Review Satisfy Update
Courtesy	Accommodating Consideration Friendliness Politeness Respect	Features	Curricula Degree Offerings Opportunities Program
Communication	Contact Inform Interact Listen Participate	Credibility	Believability Ethical Honesty Integrity Trustworthiness

Source: Adapted from Alotaibi et al., (2016)

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# Enhancing an Organization's Output through Re-engineering of Administrative Processes

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**Abstract:** This research implements a descriptive approach in preparing a theoretical framework for re-engineering administrative processes. The objective of this work is to identify the administrative processes to be considered and to quantify the benefits of applying the re-engineering processes. A field study was performed to determine the feasibility of applying the proposed framework in companies operating in Jeddah, Kingdom of Saudi Arabia. The study included a selected sample of projects from various service and manufacturing sectors. The results supported the need for re-engineering the administrative processes to help achieve tangible improvements in efficiency, productivity, and profitability.

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## 1. INTRODUCTION

Process re-engineering is one of the best management methods to reduce cost, save time and improve quality of service because it embraces the idea of considering and rethinking the organization's organizational processes, structure, and engineering to achieve tangible improvements in efficiency, productivity, and profitability.

Organizations are one of the sectors recognized for their steady growth in the face of intense competition. As these organizations experience high costs, declining revenues, and administrative profits due to local, regional and global economic conditions, they must use modern methods to reduce cost and increase profitability, quality of services, and administrative products. This study seeks to know the impact of re-engineering processes on the performance of organizations.

The objective of this work is to identify the administrative re-engineering processes and to acknowledge the motivation for applying organizations to re-engineering processes. This research aims to produce results that are of importance to decision-makers in the banking field to benefit from findings regarding the direction and continuous improvement of services. This work also seeks to address the re-engineering of administrative processes as an administrative entry for the development of the banking sector.

The population of this study consists of a random sample to answer the questionnaire, which will be an essential tool for the study. The study sample consists of general managers, department managers, and employees in private organizations in Jeddah.

The boundaries of the study were chosen so that it is possible to obtain information, distribute the questionnaire, collect information, and analyze it to benefit from this information and reach the desired results of this work. The dependent variables represent the reduction of costs and the increase in profits; the independent variables represent the rebuilding of the organizational structure, organizational culture, empowering employees, and information technology.

## 2. LITERATURE REVIEW

Re-engineering derives its name from a process involving breaking an electronic product apart to redesign it into a superior version <sup>[1]</sup>. Therefore, re-engineering involves the dismantling of an electronic product to create a better version whose efficiency and effectiveness of operation exceeds that of the original

one. Japanese companies have, over the years, used this method to create and innovate technologies. Companies gathered ready-made goods that other countries developed and manufactured. After collection, the Japanese companies proceeded to dismantle and assemble them in diverse ways that ensured the products were simple to produce, cheaper to manufacture, and easy to use. Consequently, the process that Japanese firms embraced contributed to the development of the re-engineering concept in the manufacturing sector.

The business re-engineering concept extends and re-engineers radical and rapid administrative, strategic processes, core value-added and systems, structures of organizations, and policies in a bid to increase support to workflows in addition to increasing productivity in the organization<sup>[2]</sup>. It has been defined by<sup>[3]</sup> as “a radical way of thinking of the organization, translating to the performance of things, which can be equated to the concept of innovation.” Another definition of the concept<sup>[4]</sup> is “the necessary work of the organization meant to internally restructure the operations.”

Ozcelik (2010)<sup>[6]</sup> undertook an examination of business process re-engineering (BPR) projects to see whether it improves the performance of firms through the comprehensive analysis of a data set found on prominent businesses in the United States (U.S.). Some of the measures of performance used include return on equity, return on assets, and labor productivity. It is reported by the researcher that there is increased firm performance upon the BPR projects finalized as it remains constant in the process of execution. Further, the report shows that BPR projects that were functionally focused averagely contributed more to the performance than the larger cross-functional scope. This likely indicates that the BPR project’s potential failure has the probability of increasing to surpass a given scope level. Altinkemer et al. (2011)<sup>[7]</sup> investigated whether BPR has an association with improved firm productivity and overall performance. They approached the task by analyzing firm-level panel data belonging to large firms in the U.S. and found in the Fortune 500 list between 1987 to 2008 through fixed effects as well as first differencing known to be standard methods in accounting for effects that are unobservable at the firm level. Standard variables were employed by the researchers to measure productivity and firm performance. They found that a performance variable had a significant drop in the process of project initiation. Moreover, the fixed effects results indicated that productivity and performance measures improve non-proportionally upon initiation of the project. The report also indicated that the projects of enterprise-wide BPR have an association with increased negative returns at the initiation period. However, there is a lack of evidence regarding their superiority against projects that are BPR focused in terms of performance improvement upon initiation of the project. They suggested that this is because big projects are riskier and sometimes lead to more failures.

### **2.1. Business Re-engineering**

Business re-engineering is a technique aiming to create improvement in the way processes roll out, and the efficiency in the way processes occur, ensuring that the processes are effective in achieving goals. The necessary work of the organization is to restructure internal operations<sup>[4]</sup>.

Aims of re-engineering<sup>[5]</sup> are to reduce cost performance, do away with old routine while encouraging flexibility and freedom, modify the working strategies from close supervision, embrace more powers and responsibilities, and achieve high-quality performance. Offering exceptional and fast service and initiating more integration, as well as the interdependence between single process components, are also principal re-engineering aims.

### **2.2. Six Sigma**

Six Sigma is a vital process improvement and quality management technique. According to Goh (2002)<sup>[8]</sup>, many Fortune 500 companies have adopted Six Sigma because it can help organizations to achieve considerable performance. A good example is demonstrated by the Motorola Company, which reported benefits of up to \$16 billion by using Six Sigma between 1986 and 2001 (Eckes, 2001<sup>[9]</sup>; Hendricks and Kelbaugh, 1998<sup>[10]</sup>; Motorola, 2003<sup>[11]</sup>).

Successful Six Sigma research requires direction given that scientific research is based on cumulative tradition. Thus, it is necessary first to understand existing knowledge. A critical examination of Six Sigma

following the management information has subsequently been performed. It indicates the areas potentially leading to successful insights in research.

The Six Sigma literature indicates the possibility of this concept hindering innovativeness in organizations. Six Sigma connects with process management to ensure that change and improvement occur in processes, consistent with customer needs. Processes become consistent and improve stability with Six Sigma's variation reduction. However, there may be some incompatibility between variation reduction and exploration tasks that create variation.

Benner and Tushman<sup>[13]</sup> suggested a model that describes how process management hinders innovation. The paint industry confirmed the model empirically. Noteworthy, companies with good process management features focused on exploitation. Through exploitation, organizations replicated knowledge to create success in other organizational places. Exploitation has low risk and results in clear outcomes. In contrast, exploration is risky and requires experimentation<sup>[14]</sup>. Therefore, exploitation and exploration have conflicting outcomes. Over a period, companies reduce innovativeness, as more entities file patents. The advanced connection between Six Sigma and processes may adversely impact innovation efforts.

Six Sigma implementation applies a project approach in program execution. The improvement initiatives occur as projects are contained in a master improvement program plan. For example, organizations list several improvement ideas and select an appropriate number for implementation. The selected ideas form projects, which act as the avenues of Six Sigma improvement. The decision-making in the selection of ideas for project improvement is crucial (Schroeder et al., 2008<sup>[15]</sup>; Zhang et al., 2008<sup>[16]</sup>). Strategic project selection refers to the process by which organizations choose and prioritize projects for improvement. These efforts ensure the formation of programs from the selected projects (Project Management Institute Standards Committee, 2004<sup>[17]</sup>). The process of selecting and prioritizing those projects has an organization-wide implication, and this process forms the backbone and the foundation of Six Sigma's controlling mechanism. From this process, an organization can make appropriate resource allocation decisions and program priorities. Strategic project selection helps in the creation of a balance between the aspects of exploitation and exploration.

### **2.2.1.Design for Six Sigma**

Design for Six Sigma (DFSS) is one of the critical elements of Six Sigma. It emphasizes the development of products by an organization, which have high-reliability levels and are easy to manufacture. However, few studies have examined DFSS. The existing literature focuses on engineering and statistics. Consequently, the implications of DFSS on improvement initiatives are unclear. Moreover, there are no studies that investigate the influence of DFSS on design performance.

### **2.3. Lean in Services**

Some case studies reveal that lean practices can significantly contribute to a firm's performance, even if it does not specialize in the manufacturing of physical goods. Swank (2003) [12] demonstrated the way an insurance company can apply lean initiatives to increase its performance beyond what it has ever achieved. The firm under investigation managed to improve quality and reduce lead times by standardizing procedures, organizing processes according to their relationship, and reducing the work in progress.

## **3.FUNDAMENTALS OF THE RE-ENGINEERING SYSTEM**

A critical administrative direction that leads the process of change in an organization is to make the organization start to work again and deliver a high-quality product according to the customer's specifications. Business Process Recovery (BPR) will motivate organizations to keep abreast of changes in technology and achieve a range of benefits while reducing delivery and cycle time failures. Such process re-engineering can also determine the product's ability to perform its manufacturing purpose. The essential components of the re-engineering system are fundamental rethinking, radical redesign, super

improvements, and operations.

Re-engineering of administrative processes includes both essential and radical change. The output results are vast and substantial due to changes in operations, thus, require IT involvement. The change depends on inductive rather than deductive thinking.

Re-engineering objectives for administrative processes aim to achieve customer satisfaction through a radical change in performance: namely speed and quality. It also aims to reduce cost and be superior to competitors

Re-engineering will lead to reduced failures in delivery and cycle times. It will also help to increase the efficiency and sense of responsibility and flexibility of customers, as well as improve communication with customers and communication between different functions. Such re-engineering further helps to reduce the number of unexpected and complex cases. Re-engineering will also lead to more control when dealing with emergencies. Considering these factors, we can expect that re-engineering will reduce the rate of waste and loss and cancel and merge some of the excess operations, which aim to reduce the cost significantly.

#### 4. FORMULATING THE RESEARCH QUESTIONS AND STUDY RESULTS

This study examines the feasibility of applying the process re-engineering system to companies operating in Saudi Arabia. To achieve the overall research objective, a sample of these projects was selected from various productive and industrial sectors in Jeddah. The error of the research hypotheses, and thus the conclusion of the basic result, is the possibility or inability to apply the method of re-engineering operations in companies operating in Saudi Arabia.

##### 4.1. Objective

The main objective of the field study is to identify the extent to which the process re-engineering method can be applied by identifying some of the bases and methods of reducing costs and developing products, as well as realistically fulfilling customers' wishes. This goal is achieved through a sub-objective, namely the identification of suitable Saudi environment conditions regarding the possibility of applying the re-engineering process by administering a questionnaire or undertaking personal interviews. Moreover, the current research will attempt to understand the obstacles limiting the use of this system in the Saudi environment.

**Table 1: Industrial projects that have been subjected to the field of research and the responses adopted**

1.	High Food Company (REFCO)	Private sector
2.	Savola Company	Private sector
3.	National Company for biscuits and confectionery	Private sector
4.	Modern Dairy Co. (Cortina)	Private sector
5.	National Food Industries Company	Private sector
6.	Manufacturing National Glass & Mirrors Co., Ltd.	Private sector
7.	Mohammed Ali Abu Dawood Company (Clorox)	Private sector
8.	Nabco Plastic Manufacturing Company	Private sector
9.	Aluminum Products Co., Ltd.	Private sector
10.	Jamjoom Metal Products Co	Private sector
11.	Al Yamama Modern Industries Co. Ltd.	Private sector
12.	Saudi Electrical Industries Company	Private sector

#### 4.2. Design Questionnaire

The questionnaire contained four sets of questions. Each of these four sets was designed to answer some critical information to reach the search results. The first set of questions identified information for the respondents and information about the projects which were subjected to the sample of the research. The second group of questions was identified through the validity or error of the first hypothesis of the research. The third group was obtained through the validity or error of the second hypothesis of the research. The fourth group of questions related to the health or error of the third hypothesis.

#### 4.3. Questionnaire

A total of 2,160 questionnaires were distributed to industrially advanced projects in Jeddah. Responses were obtained from 35 projects, with a questionnaire to 3 forms from each of the projects that responded. The number of forms was 79 ones. Eleven forms were not answered objectively enough. The research sample was chosen from the departmental managers and the various departments that have a relationship.

**Table 2: The percentage of individuals who filled out the questionnaire**

<b>Management</b>	<b>Frequency</b>	<b>percentage</b>
Financial management	21	30.9%
Production management	14	20.6%
Cost management	19	27.9%
Engineering Design Management	1	1.5%
Marketing Management	11	16.9%
Customer Service Management	2	2.9%
<b>Total</b>	<b>68</b>	<b>100%</b>

#### 4.4. Statistical Methods

First, descriptive statistical methods will be used through the frequency and percentages of search variables and the mean calculated to measure research sample variable trends such as degrees of importance and comparison. Finally, a cross tabulation is used to see the frequency distribution and percentages of two variables linked to each other.

Second, the Mann-Whitney U test will be performed to test intrinsic differences between two averages. It is a non-parametric test (Test-T), which is used to determine the extent of statistically significant differences between two (or more) samples.

Finally, testing of correlation coefficient (Spearman). This is a test used to determine the degree (strength) of the correlation between two variables or two sets of data, as well as to see the extent of the existence of significant differences in the order of importance of two variables or two sets of data.

The responses and information contained in the feedback forms were analyzed using the above-mentioned statistical methods. These statistical methods were conducted using the statistical analysis program (SPSS). The data analysis results are identified using the results of the information analysis of the questionnaire fillers and clarified. Scientific qualification and specialization for those who fill out the questionnaire are required.

**Table 3: Distribution of the research sample according to the qualifications and scientific degrees**

Qualification	Accounting Sciences		Administrative Sciences		Engineering sciences		Other		Total	
	F	%	F	%	F	%	F	%	F	%
University	24	82.8	10	90.9	16	72.7	6	100	56	82.4
Postgraduate	5	17.2	1	9.1	6	27.3	0	0	12	17.6
Total	29	42.6	11	16.2	22	32.4	6	8.8	68	100

Table 3 shows that the highest percentage of individuals who fill out the questionnaire are individuals who specialize in accounting sciences (42.6%). Of these, university graduates make up 82.8%, and those with postgraduate studies make up 17.2%. The sample members in the engineering sciences account for 32.4% of the total respondents, 72.7% of whom have a bachelor's degree, and 27.3% of whom have postgraduate studies. Respondents who specialize in administrative sciences comprise 16.2% of the total sample; 90.9% are graduates with a bachelor's degree, and 9.1% hold postgraduate qualifications. The percentage of individuals from other disciplines is 8.8%, all of whom hold a bachelor's degree; no other majors were reported.

#### 4.5. Data Analysis Results

The above-mentioned statistical methods were used to analyze the responses and information contained in the feedback forms. These statistical methods were conducted using the statistical analysis program (SPSS), and the data analysis results identified.

##### First Hypothesis:

Some Saudi industrial and service projects have the potential to re-engineer operations to reduce costs. In order to verify the validity or error of the first hypothesis of the research, the results will be analyzed using the following tables:

**Table 4: Distribution of the research sample according to the extent of the possibility of re-engineering**

The extent to which process re-engineering can be applied	F	%
Application of style	19	54.3
Do not apply style	16	45.7
Total	35	100

Table 4 shows that the percentage of projects that have the potential to implement the target cost system is 54.3%, while the percentage of projects that stated that they have no possibility of applying the system is 45.7%.

##### Second Hypothesis:

The application of process re-engineering reduces industrial and service company project costs. Degree of the importance of reduction Analysis of the views of the research sample from projects with potential that do not have the possibility of applying the system according to the degree of importance given to reduce costs. The results will be analyzed using Table 4 to verify the validity or error of the first hypothesis of the research.

Table 4: shows that the percentage of projects that have the potential to implement the target cost system is 54.3%, while the percentage of projects that stated that they have no possibility of applying the system is 45.7%. We then determine the results of the questionnaire analysis via the application of process re-engineering, which reduces both industrial and service company project costs, until the second research

hypothesis is validated or wrong. The following tables show the findings:

**Table 5: Analysis of the views of the research sample from projects with potential and those that do not have the possibility of applying the system according to the degree of importance given to reducing costs**

The importance of reducing costs	Application of style		Do not apply style	
	F	%	F	%
Very large	27	75	23	71.9
Great importance	6	16.7	9	28.1
Medium importance	3	7.3	0	0
Poor importance	0	0	0	0
Total	36	100	32	100
Average	4.67		4.72	

The above table shows that most projects that have potential and those that cannot implement the system are very important to reduce costs, with 75% and 71.9% of the projects having the potential and having no possibility of applying the process, respectively. The significance of the significant reduction is 16.7% and 28.1% of projects that have potential and that have no applicability, respectively, while projects that give medium importance to cost reduction have emerged with 7.3% of projects that have the potential to implement the target cost system.

The Mann-Whitney U test is used to analyze the significance of the difference between projects that have potential and those that cannot apply the system according to the degree of importance given to reducing costs.

**Table 6: Mann-Whitney test results analyzing the significance of the difference between projects that have potential and those that cannot apply the re-engineering process according to the degree of importance given to reducing costs**

Importance	$\delta$	Z test	Level of significance
Reduce costs	0.943	0.072	none

**Table 7: Analyzing the views of the research sample from projects that have potential and those that cannot apply re-engineering processes according to the average degree of importance given to the methods of reducing costs**

Methods of reducing costs	Application of style		Do not apply style	
	Average	ranking	Average	ranking
Look for extravagance and disposal	3.97	1	3.94	1
Negotiate with suppliers on prices of raw materials	3.83	5	3.87	3
Avoid mistakes and defects using Six Sigma	3.92	2	3.81	6
Use the JIT method	3.80	6	2.77	7
Minimizing the utilization of waste materials and recycling	2.91	10	3.09	10
Cancel activities that do not add value	3.29	9	3.25	9
Continuous improvement	3.8	6	3.87	3
Eliminate storage wastage	3.59	8	3.92	8
Delivery time	3.92	2	3.92	2
Reduce time, labor and materials (lean)	3.86	4	3.86	5

By using the Spearman correlation test, the correlation coefficient value is 0.098 at a significant level of 0.001, which is less than 0.05. There is an agreement between projects that have potential and those that do not apply the style, enabling the ranking of the importance of cost reduction methods.

**Table 8: Mann-Whitney U test results analyzing the significance of the difference between projects that have potential and those that do not apply the style according to the importance of the reduction methods used**

Methods of reducing costs	Z test	$\hat{\rho}$	Level of significance
Look for extravagance and disposal	0.72	0.472	none
Negotiate with suppliers on prices of raw materials	0.476	0.634	none
Avoid mistakes and defects using Six Sigma	0.254	0.190	none
Use the JIT method	0.667	0.799	none
Maximizing the utilization of waste materials and recycling	0.504	0.505	none
Cancel activities that do not add value	1.547	0.614	none
Continuous improvement	0.657	0.122	none
Eliminate storage wastage	0.150	0.511	none
Delivery time	0.78	0.188	none
Reduce time, labor and materials (lean)	0.697	0.486	none

### Third Hypothesis

The target cost system provides important information that helps in product development. Table 9 lists the data analysis.

**Table 9: Analysis of the views of the research sample from projects that have the potential and those that have no possibility of applying the system according to the reasons for the development of product designs**

Reasons for product development	Application of style		Do not apply style	
	F	%	F	%
Aging every year	22	40.7	15	33.3
Customers do not like the product	12	22.2	9	20
High product costs	12	22.2	14	31.11
Low quality	8	14.9	7	15.56
Total	54	100	45	100

The above table shows that industrial enterprises, whether or not capable of implementing the system, often develop their products based on obsolescence (i.e., the expiration of a specific time for the presence of the product in the market) – 40.7% and 33.3% for each project that has the potential or does not have the possibility to apply the system, respectively.

The second factor is the high-cost product development factor, with 22.2% for projects that have the potential and 31.11% for projects unable to implement the system. Moreover, the development process was carried out if the product was not accepted by customers – 22.2% and 20% by projects that had the potential and those that could not implement the system, respectively. It also appeared in third place and the fourth rank of the two types of projects, respectively. The reason for product development relates to the quality of the product being below the required level. This factor is 14.9% for projects that have the possibility to apply the style and 15.56% for projects that do not have the possibility to apply the system.

**Table 10: Analysis of the views of the research sample from projects that have the potential or do not have the possibility to apply the style according to the average degree of development**

Control processes to achieve lean	Application of style		Do not apply style	
	Average	ranking	Average	ranking
Employment	4.78	3	4.69	3
Costs	4.78	3	3.72	5
The quality	4.89	2	4.91	1
Process of production	4.69	5	4.66	4
Achieving customer needs	4.91	1	4.75	2

Table 10 shows that projects with the potential to implement the target cost system are primarily concerned with monitoring customer satisfaction. This control process has a high average of 4.91. The second concern relates to quality control (4.89), the third to the control of labor and costs (4.78 each), and the final rank to the control of the process of production (4.69). Projects stating that there is no possibility to apply the system are concerned with the control of achieving the customers' desires (4.75), the control of labor (4.69), the control of the production process (4.66), and cost control (3.72). From the above, we found that projects that have the possibility and those that do not have the possibility of application are significantly interested in the control processes. The importance of these processes is between 4.91 and 3.72. We also found that projects that have the potential to apply the target cost system are concerned with cost control much more than projects that are not capable of implementing the system.

In order to determine whether the order of importance given to the control processes is agreed by the projects that have potential or that cannot apply the system, the Spearman correlation test was performed. Results indicate that the correlation coefficient value was 0.872, with a significance level greater than 0.05. This suggests that there is a difference between projects that have the potential and those that do not have the possibility of application in terms of the degree of importance given to the control processes. It also emerged that projects with the potential to apply the system are primarily concerned with controlling the wishes of customers.

## 5. CONCLUSIONS AND RECOMMENDATIONS

All employees operate for the development of the manufacturing plan, decision-making, and completion of tasks. Six Sigma and lean in service reduces inflation and costs and the percentage of defects and also eliminates waste in the production process. Finally, the process of product development using target costs goes hand in hand with the process of cost reduction, which is an automatic result and does not require additional effort.

### 5.1. Results

It is evident that companies that implement re-engineering change radically in all technical, economic, administrative, and social accounting aspects. The application of the re-engineering process as an input to cost reduction has resulted in a new, less-costly situation. Thus, there is a fundamental correlation between process engineering and cost reduction. Finally, the effect of change management determines the relationship between process engineering and cost reduction in private companies in Saudi Arabia.

### 5.2. Recommendations

Companies can adopt the re-engineering method because of its benefits in reducing costs, increasing competition for companies, and its advantages. It is necessary to develop cost accounting systems that are in line with the re-engineering of corporate practices. Companies operating in the Kingdom of Saudi Arabia, especially private companies and institutions, must follow the process of re-engineering processes so that

they can achieve the winner of the profits and increase their competitive advantage.

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## Law Enforcement's Usage of Business Intelligence Collaboration

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**Abstract:** In recent years, current events have often coined the term “officials are gathering business intelligence.” The purpose of this research paper is to gain an understanding of what business intelligence is and to investigate the collaborative usage of business intelligence within law enforcement.

First, the varied and many definitions and scopes of business intelligence will be explored and explained, with particular relevancy to law enforcement. The paper will then provide an overview of collaborative business intelligence practices within law enforcement. The paper will support current research, which suggests that law enforcement in the United States are using some form of business intelligence to assist with their cases and reported crimes. For investigators, this translates into an increase in closed cases.

The last part of the paper will focus on specific collaborative business intelligence tools that can be utilized by law enforcement. Numerous crimes are committed and linked to multiple locations and perpetrators. Collaboration tools can be used beneficially within departments and with outside agencies to identify patterns, trends, and relationships not normally discovered through individual analysis.

*Keywords:* business intelligence, BI collaboration tools, law enforcement

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### 1. INTRODUCTION

The term Business Intelligence (BI) was first introduced into society in 1865 as an anecdotal phrase. It was used to describe the benefits of gathering and acting upon information as a competitive advantage. In 1958, International Business Machines (IBM) described BI as technology used to collect, analyze, and translate data into meaningful information, which should be acted upon before the competition. For the next two decades, interpretation of business intelligence data was stifled with limited access to fragmented data sources. In the 1980's, the power and potential of BI was unleashed with the birth of relational databases, decision support systems, and BI tools. These developments made it possible to gather and organize massive amounts of data from a single data source, saving time and money and streamlining analysis, translation, and decision-making processes. In the late 1980's, BI businesses cropped up in response to the growing interest to have more efficient BI tools. By the late 1990's and early 2000's, more simplified and user-friendly tools were developed, which provided greater functionality and productivity. Today business intelligence is all about Big Data and Analytics. Numerous software vendors have developed sophisticated products, which provide “reporting capabilities, dashboards, advanced visualization, and end-user self-service that are given the highest priority ... in enterprises focused on making BI a strategic foundation for growth” (Columbus, 2017, para. 7).

### 2. BUSINESS INTELLIGENCE DEFINED

It is essential, first, to establish the difference between “data” and “information.” Data, commonly referred to as raw data or unprocessed data, is data that has not been analyzed or processed. Data can be any character, text, words, numbers, symbols, pictures, sound, or video. Once the data is analyzed, processed, organized, or structured, it becomes information that is useful and meaningful. Information in

the context of law enforcement is defined as “pieces of raw, unanalyzed data that identifies persons, evidence, events, or illustrates processes that indicate the incidence of a criminal event or witnesses or evidence of a criminal event” (International Association of Directors of Law Enforcement Standards and Training, 2004, p. 9).

From its inception to present day, business intelligence has been defined using an array of buzzwords and technical terms. In its most simplistic form, “BI means the use of computing technologies for the identification, discovery, and analysis of business data” (Techopedia, 2017, para. 1). Expounding upon this foundational description, BI is often coined as an “umbrella term.” These definitions reference terminology such as applications, infrastructure and tools, and best practices to access and analyze information. Other explanations refer to BI as “a set of methodologies,” “getting the right information to the right people at the right time,” “a managerial philosophy,” “a system that turns data into information,” and “an architecture and collection of integrated operational and decision-support applications and databases.” Perhaps the most encompassing definition refers to business intelligence as “the various solutions for enhancing the overall business performance” (Big Data Made Simple, 2014, paras. 2-20).

From a law enforcement perspective, the definition of business intelligence is broadened to include criminalities, crime trends, security trends, extremists, and terrorists. One current definition of law enforcement intelligence is “the end product (output) of an analytic process that collects and assesses information about crimes and/or criminal enterprises with the purpose of making judgments and inferences about community conditions, potential problems, and criminal activity with the intent to pursue criminal prosecution or project crime trends to support informed decision making by [law enforcement] management” (Smith, 2014, p. 59).

With the advent of digital technologies, the collection, analysis, and sharing of global business data is referred to as “Intelligence-Led Policing (ILP)” or “criminal intelligence.” ILP activities are strengthened with the utilization of business intelligence data analysis. Information that is analyzed, credible, and reliable ensures that decisions are formulated based on factual criteria. For example, an analysis of crime trends using historical data can be used to predict the likelihood of further occurrences in a particular area. The International Association of Law Enforcement Intelligence Analysts (ALIEA, 2004) states that “taking information collected in the course of an investigation, or from internal or external files, [results in] ... arriving at something more than was evident before. This could be leads in a case, a more accurate view of a crime problem, a forecast of future crime levels, a hypothesis of who may have committed a crime or a strategy to prevent crime” (p. 12).

Comprehensive global business data can support and increase the effectiveness of ILP activities by transforming data into actionable information. Law enforcement agencies utilize four areas of analytics to identify, anticipate, and halt criminal activities. Investigative analysis detects linkages among seemingly unrelated enterprises or individuals. Strategic analysis proactively evaluates business connections and crime activity. Monitoring analysis proactively tracks businesses and individuals for suspicious or unusual activity. Predictive analysis identifies watch lists, sanctions, and recognizes patterns of unlawful business practices.

The International Association of Crime Analysts (IACA, 2014) supports “traditional definitions of tactical, strategic, and administrative crime analysis” (p. 1). Crime intelligence analysis refers to data analytics relating to individuals, organizations, and networks. Tactical intelligence analysis refers to the short-term assessment of investigative initiatives, tasks, and law enforcement resources. Strategic intelligence analysis refers to the long-term assessment of trends, hot spots which define areas of high occurrence versus areas of low occurrence, and problem analysis used to identify cause and effect. Administrative intelligence analysis refers to organizational analytics relating to the needs of agencies, government, and the community.

The Federal Bureau of Investigation (FBI) Office of Intelligence (OI) also provides a functional definition of business intelligence. Former FBI Deputy Assistant Robert Casey states “in the law enforcement/national security business, [intelligence] is information about those who would do us harm in the form of terrorist acts or other crimes, be they property crimes or violent crimes. ... [The FBI OI] produces both ‘raw’ (or un-evaluated intelligence) and ‘finished’ intelligence products (those that report

intelligence that has had some degree of analysis)”; (International Association of Directors of Law Enforcement and Training, 2004, p. 13).

Regardless of the multiple definitions, interpretations, and strategies surrounding business intelligence, a common theme resonates among organizations, industries, and individuals that define and utilize business intelligence. Empirical analysis must be performed on the data before it can be classified as intelligence or actionable information. Definitions often become problematic because of deep-rooted tradition and context upon which they have been built and understood within specific law enforcement agencies. As police agencies expand their reach of criminal activity analysis, both nationally and internationally, it is important that all parties involved adopt a common set of definitions and terms to minimize confusion, and provide a framework for working cohesively, efficiently, and productively.

### **3. COLLABORATIVE BUSINESS INTELLIGENCE WITHIN LAW ENFORCEMENT**

Organizations are always on the lookout for a competitive edge, and this is no less true for law enforcement agencies, as they look to newer and better investigative tools. Currently, such agencies are embracing the use of business intelligence to improve outcomes and improve safety in their communities. Law enforcement has discovered unique ways of combining crime scene and demographic data to better analyze the evidence and make predictions about it to prevent future illegal activity. Although the terms business intelligence and analytics are often used interchangeably, there is a distinction (Foote, 2017). Business intelligence uses technology in order to enhance decision-making, while analytics is a broad term of collecting and storing data and has become a general term “covering data warehousing, enterprise information management, business intelligence, enterprise performance management, and governance” (Foote, 2017, para. 12). The next section will focus on the specific uses of business intelligence as it applies to law enforcement agencies.

#### **3.1. Predictive Crime Mapping**

Predictive crime mapping is one area where law enforcement agencies are utilizing business intelligence tools to gather and interpret relevant data in order to better predict (and prevent) not only crimes but also offenders. Law enforcement agencies’ databases have traditionally focused on integrating data nationally to include fingerprints, DNA, and other evidence collected during investigations. The focus has now shifted from crime scene evidence to resolving individual criminal activities, and it has recently been utilized to assess the appropriate use of law enforcement professionals and emergency vehicles, to identify potential reoffenders, and to anticipate new areas of criminal activity that can be reported to legislators (Kovacevic, 2018). For example, predictive crime mapping may help pinpoint where repetitive crimes occur and when they will most likely take place (Rosser, Davies, Bowers, Johnson, & Cheng, 2017). Fitterer, Nelson, and Nathoo (2015) piggyback on this assertion finding that offenders prefer to practice criminal behavior in areas known to be advantageous for their pursuits. Due to its perceived success and enhanced decision making, its popularity is growing. While such analytics are now practiced in the United States, other nations are taking notice and are beginning to develop their own similar measures (Kovacevic, 2018). They are using the data to create “predictive crime mapping,” in which data is used to create grid-like GPS maps that detail types of criminal activity and their dates, times, and locations (Kovacevic, 2018). This allows agencies to create interactive maps in order to redirect resources most efficiently and better predict when and where crimes will occur (Kovacevic, 2018). Predictive crime mapping allows agencies to more efficiently place officers and increase response rates (Leigh, Dunnett, & Jackson, 2019). In fact, in the United Kingdom, research shows that these predictive crime maps have allowed law enforcement to predict criminal activity 10 times more effectively than police alone (Kovacevic, 2018). The practice of predictive crime mapping will likely only become more widespread.

Predictive crime scene mapping involves more than crime scene data. It combines the crime scene data with demographic data in order to better predict instances of criminal behavior and the criminals, alike. Additionally, such data analytics are allowing law enforcement agencies to collect data on historical

criminal activity in order to identify those who may reoffend by focusing on the time, location, and victim characteristics to associate such activity with the responsible person (Kovacevic, 2018). While this practice is certainly not infallible or precise, it has shown to be effective in about 98% of individuals who present a low risk of reoffending (Kovacevic, 2018). With those at a high risk of reoffending, the success was slightly lower at 88% (Kovacevic, 2018). These results are encouraging, as they allow agencies to more accurately predict when and where crimes will occur (Kovacevic, 2018). It is anticipated that this trend will continue to grow as more data are collected and more agencies take part (Kovacevic, 2018).

### **3.2. The Case of the Los Angeles Police Department.**

One specific agency is using data to not only predict criminal activity but also to rate the level of crime (Lapowsky, 2018). The Los Angeles Police Department, since 2011, has been collecting data on such criminal behavior using it to identify individuals who commit crimes over a two year period and rate the level of the crime using the statistics from the arrest records (Lapowsky, 2018). This has allowed the Los Angeles Police Department to more effectively monitor these individuals, as they are better able to predict reoffences (Lapowsky, 2018). Opponents of this practice, however, insist that “predictive policing” is simply a new tactic of racial profiling (Lapowsky, 2018). Experts believe that such algorithms are only as effective as the quality of the data entered into it (Lapowsky, 2018). They suggest that data entered into the system may be biased and have a direct and disproportionate impact on sentencing and bail (Lapowsky, 2018). Indeed, Jefferson (2018) found that such practices gave a sense of legitimacy to the practice, thus supporting increased use of such maps and their disproportionate relationship with people of color. In fact, research has shown that such measures increase the police presence in areas of reported crimes, and causes individuals in those communities to feel “targeted” by law enforcement (Lapowsky, 2018). The next section will look at law enforcement’s use of data analytics.

## **4. AREAS OF LAW ENFORCEMENT IMPROVEMENT THROUGH DATA ANALYTICS**

Analytics are used in a variety of ways to collect and organize historical information, to anticipate market trends, provide more accurate advice, and to interpret that data in real time in order to get ahead of the competition (Foote, 2017). Criminal activity presents a huge economic cost to communities (Mills, 2017). Reducing crime therefore reduces costs. Using data analytics allows law enforcement agencies to more effectively predict and prevent crime from happening (Mills, 2017). Such analytics can also be used to interfere with cyber-crimes as well by collecting and interpreting data to track and coordinate malicious activity, effectively reducing costs in these crime ridden areas (Mills, 2017).

An interesting byproduct of the practice of using data analytics to predict and interfere with crime is that it can increase the amount of social services in communities that have been hit the hardest by disaster affected areas, such as flood zones, to map and monitor these locations (Mills, 2017). Such data can be used to create new areas of training for employees and involve nonprofit organizations in those areas to improve programs and services for the individuals directly affected by the disasters (Mills, 2017). These improved responses can mitigate the effects of the disasters through faster delivery of assistance to bring down unemployment and to provide job training and allocation of resources (Mills, 2017). Continued improvement in this area may lead to widespread global response to illegal activities (Mills, 2017).

## **5. PRACTICES OF PREDICTIVE POLICING**

Some agencies operate on the assumption that predictive policing leads to reduced misdemeanor crimes, which could then in turn lead to reduced felonies (Haskins, 2019). Agencies use the data to create community maps that isolate criminal activity to individual locations and even houses (Haskins, 2019). These maps are created on the assumption that when certain crimes are committed at a particular time, they may be likely to occur again in the same pattern (Haskins, 2019). An overall timeline can be generated to look at communities through various timeframes to establish patterns and trends and to create a historical

record of criminal activity (Haskins, 2019). In fact, such maps can be used to distinguish high crime areas relative to low crime areas, thus allowing the appropriate allocation of resources to those areas (Kalantari, Ghezlbash, Ghezlbash, & Yaghmaei, 2019). One criticism of this approach is that it is inherently biased, as communities that are heavily patrolled will report disparate data (Haskins, 2019). “There really hasn’t been much external validation of whether the technology works, what it even means, what are you comparing it to, and there’s been a lack of research and science on that” (Haskins, 2019, para. 9). Yet proponents suggest that any reduction in crime positively impacts everyone, criminal and victim alike (Haskins, 2019). They also note that, while law enforcement has always used predictions to anticipate illegal behavior, data analytics and the use of predictive policing enhance those predictions (Haskins, 2019). Yet opponents have found cases where officers use the data to target specific individuals unnecessarily (Haskins, 2019). In fact, they allege that over policing in some areas could increase the likelihood of gun related deaths, as increased police presence often leads to higher rates of shootings (Haskins, 2019).

A popular use of predictive policing was the “broken windows” approach used widely from 1980’s and until 2012-2014 (Haskins, 2019). Officers in communities where “broken windows policing” used incidents of broken windows to pursue investigations into criminal activity and prosecuting low level violations, “such as public urination or intoxication as criminal rather than civil offenses” (Haskins, 2019, para. 24). Yet, upon investigation in 2016, “broken windows policing” was not found to be effective in reducing violent crimes and disproportionately impact people of color (Haskins, 2019).

## **6. PREDICTIVE POLICING PRACTICES: BENEFITS AND RISKS**

### **6.1. Benefits**

Predictive policing is defined as the use of collected data to more precisely predict the types of crime that are likely to happen as well as when and where they will occur (Meijer & Wessels, 2019). Such data are also used to predict potential victims of those crimes (Meijer & Wessels, 2019). An interesting aspect of such analytical practices is that law enforcement agencies are able to incorporate a wide variety of data, whereas traditional policing activities focused only on what was uncovered during the investigation (Meijer & Wessels, 2019). Research suggests that using broad forms of data to investigate and predict crime leads to improved decision-making and planning activities (Meijer & Wessels, 2019). Additionally, use of data analytics allows agencies to coordinate activities to predict criminal behavior by identifying known actors and removing factors leading to it (Meijer & Wessels, 2019). Little research, however, has supported this notion (Meijer & Wessels, 2019).

One specific area of improvement in applying predictive policing is that it allows agencies to use a wider range of historic crime data to more effectively and efficiently allocate resources and personnel (Meijer & Wessels, 2019). This is done through identification of areas of high crimes to predict where criminal activity is likely to take place (Meijer & Wessels, 2019). Such practices include identifying not only the areas of criminal activity but the times it most frequently takes place in order to anticipate and prevent it (Meijer & Wessels, 2019). This may lead to improved patrol routes and more effective distribution of law enforcement personnel (Meijer & Wessels, 2019). Predictive policing may also be useful in identifying potential offenders through the use of demographics and patterns of behavior (Meijer & Wessels, 2019). For example, one study used social media data and criminal statistics to distinguish otherwise lawful individuals who associate with known offenders and to what degree (Meijer & Wessels, 2019). Research on the efficacy of such practices remains limited, although two encouraging areas of success are the identification of types of behavior and improved police response to them (Meijer & Wessels, 2019). One study suggested that police placement in the community posed a reliable deterrent to illegal activity (Meijer & Wessels, 2019).

### **6.2. Risks**

While law enforcement agencies will likely continue to pursue such data analytics, they do come with some identified risks. One such criticism is that, although entrenched in statistics, it remains impossible to fully understand the implications of them as a result of the divergent use of predictive policing models

(Meijer & Wessels, 2019). Errors in interpretation of the data can have disastrous consequences (Meijer & Wessels, 2019). Some experts suggest that the use of predictive policing indicates correlation but not causation (Meijer & Wessels, 2019). This may present agencies with conflicts through lack of transparency and accountability (Meijer & Wessels, 2019). Gemma (2018) cautions that agencies must critically evaluate the data to ensure it is appropriate for the mapping process. When officers do not fully comprehend what the data suggest, they may act in a manner inconsistent with the offense (Meijer & Wessels, 2019). Bennett Moses and Chan (2018) recommend agencies submit software to be vetted through reliable third parties to increase transparency in the use of predictive crime mapping in racially diverse areas. The research also suggests that focusing on known offenders could lead to disparate treatment encouraging discrimination, thus potentially leading to increased recidivism (Meijer & Wessels, 2019). The unintended consequences of predicted policing include over policing of some areas while areas of less crime and patrols experience greater economic advances leading to greater inequality (Meijer & Wessels, 2019). Finally, the use of individual social media and GPS data presents a threat to privacy and ethical treatment (Meijer & Wessels, 2019). Hardyns and Rummens (2018) discussed issues with the wide variety of data collected and the ethics of where and how it was harvested that could impact privacy concerns with the use of such data. These factors may compromise boundaries on what is appropriate and ethical (Meijer & Wessels, 2019). Researchers suggest that more training of police officers will be needed to counter such risks and to reestablish trust in communities (Meijer & Wessels, 2019). More research is needed in this area in order to truly understand predictive policing efficacy (Meijer & Wessels, 2019). One thing is, however, certain: unless law enforcement officers understand and correctly interpret the data, effectiveness and accountability will be undermined (Meijer & Wessels, 2019).

Another critique of predictive policing and the use of data analytics are the relationships between the law enforcement agencies and the corporate entities providing the data, entering into undisclosed agreements and using proprietary information, issues of transparency with regard to the entire process remain an issue (Haskins, 2019). The privatization of the data collection also raises concerns about accountability and transparency (Haskins, 2019). One study found that many law enforcement agencies relied on a single data technology company, further suggesting lack of transparency and accountability (Haskins, 2019). This single entity reported storing data indefinitely unless asked to purge it by individual law enforcement agencies, potentially leading to the use and sale of the data (Haskins, 2019). Additionally, users of such data analytics are reliant upon the technical support technicians who may or may not have the agency's best interests at heart (Haskins, 2019). Opponents of such practices also note that it is still a very new use of technology, yet it is given priority over traditional policing activities; too much is still unknown (Haskins, 2019).

## 7. CONCLUSION

Predictive policing is defined as the use of collected data to more precisely predict the types of crime that are likely to happen as well as when and where they will occur (Meijer & Wessels, 2019). Predictive policing is becoming more and more popular and will continue to expand in its application, as its effectiveness is far too tantalizing to abandon. Communities are always looking to enhanced and improved crime prevention strategies. Agencies have found that they are able to coordinate a wide range of data to more effectively evaluate the circumstances surrounding the crime thus improving decision-making and planning. Predictive policing also allows for agencies through the identification of the actors and removing opportunities to reoffend. Some suggest that it may also help better construct patrol routes and officer placement through the use of demographics and trends. A noted benefit was the suggestion that the appropriate placement of officers in communities decreased criminal activity. Opponents of such practices, however, have a laundry list of objections, including bias, racism, errors, discrimination, privacy, ethics, over-policing, security, its application, and issues with transparency and accountability in their application and the use of private corporations to supply the data. While current research and practices on predictive policing is promising, it is clear that further research is needed to fully understand the implications and

ramifications of it, especially as it relates to the application of policing activities and the accountability and transparency of them.

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## Study of Kinematic and Kinetic Aspects of Mechanisms Using Tools of CAD Solid Modelers

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**Abstract:** In engineering education, the kinematic and kinetic study of mechanisms is a subject that is as challenging to teach as it is to learn. Modern computer aided design (CAD) and solid modeling software, such as SolidWorks, enables the synthesis, analysis and evaluation of mechanisms throughout the design process and in greater detail than has ever been available. In the past, a designer carefully selected a limited number of instants in time where position, velocity, acceleration, force and torque were painstakingly determined to evaluate performance. This was a complex process that required skill and attention to detail. Now, using solid modeler tools such as Sketch, Assembly and Motion Study, these parameters can be continuously evaluated throughout the cycle of a mechanism whether it be simple or complex. As an example, a relatively simple rocker linkage is modeled. The results of motion parameters at specific stages of the cycle are determined theoretically and compared to those obtained using the solid modeler.

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### 1. INTRODUCTION

The design ‘stem’ of mechanical engineering involves statics (Plesha, 2010), dynamics (Beer, 2019), vibrations (Thomson, 1998), design processes (Ullman, 2015), the mechanical design of machine elements (Budynas, 2014), manufacturing engineering (Elshennawy, 2015), and the focus of this paper, mechanisms (Norton, 2012). The study of mechanisms involves synthesis (Section 2), kinematics (Section 3) and kinetics (Section 4), all of which will be accomplished, in this paper, using tools available in computer aided design (CAD) modeling software, namely SolidWorks (Howard, 2018) (SolidWorks, 2020). Synthesis is the process of first creating a conceptual mechanism that can achieve some required path of motion. Formal methods of synthesis, where available, must be utilized. Synthesis using the sketch tools in SolidWorks will be illustrated. Kinematics is the study of any mechanism to gain a better understanding and control of parameters such as velocities and accelerations involved in motion. Synthesis is also kinematics with a focus on position. A method combining the kinematic equations and vector polygons using SolidWorks sketches will be used to study the kinematics at the starting position of a synthesized mechanism without loss of generality. To study kinematics over a period of motion of the mechanism, it is more efficient to use the Motion Study tool within SolidWorks. In this study, sketches alone are insufficient, solid models are required. The results of both methods, for a particular position of the mechanism or instance in time, can then be compared. When the results match, the accuracy and equivalence of the studies is demonstrated. To quantify the forces and torques that interact to produce motion parameters, such as position, velocity and acceleration, a kinetic study must follow. A theoretical kinetic solution of the starting position, using free-body-diagrams and Newton’s Laws of Motion, is illustrated. As with the kinematics, to study the kinetics over a period of motion, a solid model and the

Motion Study tool is used. Results of the solid model obtained for the same position and instance in time as theoretical solution, when compared, will confirm the accuracy of the model.

## 2. SYNTHESIS OF A MECHANISM

The motion to be achieved through a mechanism is a rocker with an angular displacement that is between 60 and 65 degrees. The rocker movement needs to be in the second quadrant, be 10 inches long between pin centers and be part of a Grashof crank-rocker 4-bar mechanism. The fixed link of the 4-bar mechanism needs to be horizontal and 19 inches long between pin centers. Some kinematic conditions, such as the crank's initial position, initial angular velocity, angular velocity over time and initial angular acceleration are available and provided during the kinematic study. Loads on the mechanism are also available and provided during the kinetic study.

It is only possible to synthesize a mechanism to meet the above requirements if they are all realizable. Since there is no objective way to determine this ahead of time, there may need to be a certain amount of give and take in the requirements during the synthesis process. An efficient way to implement the graphical methods established for synthesizing a mechanism is to use the sketch tools within SolidWorks. Figures 1 through 4 illustrate the outcome of using the sketch tool following methods outlined by Robert L. Norton in *Design of Machinery* on pages 102-119 (Norton, 2012).

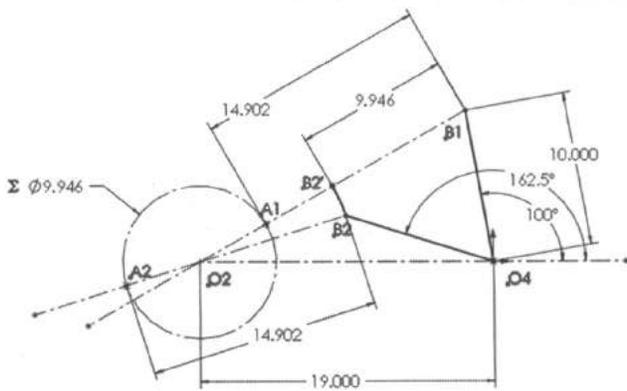


Figure 1. Synthesis of the basic mechanism

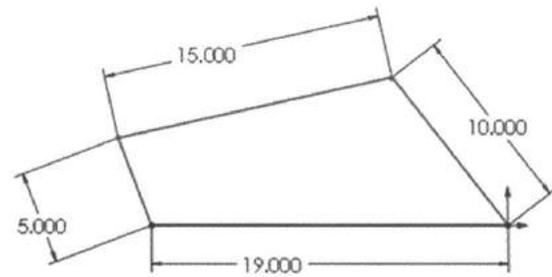


Figure 2. The refined basic mechanism

The basic mechanism shown in Figure 1 meets the stated requirements; the angular displacement of the rocker is 62.5 degrees, and the displacement is within the second quadrant. This mechanism is a Grashof crank-rocker because the sum of the shortest and longest links is less than the sum of the lengths of the other two links and one of the links next to the shortest link is grounded. Hence, having met the Grashof condition, the crank can completely rotate, and the rocker oscillates between the extremes shown. Since integer values are preferred for the length of links, the basic mechanism can be adjusted by rounding the crank and coupler lengths to the closest integers as shown in Figure 2. A quick check of the criteria confirms that the Grashof conditions are still met.

The sketches shown in Figures 1 and 2 were drawn in SolidWorks as separate sketch layers, one on top of the other using “Hide” and “Show” options, to facilitate faster construction and changes. The importance of synthesis and the outcome achieved thus far in this example should not be underemphasized to engineering students because real-world challenges are a lot more about synthesis than analysis even though most engineering courses focus on the analysis of a given design. Practicing engineers are often solely responsible for the synthesis stages of design work.

### 3. KINEMATICS OF THE SYNTHESIZED MECHANISM

The synthesis process resulted in a skeletal linkage that can now be used for further kinematic and kinetic studies. The mechanism is grounded using a fixed link, Link 1. Without loss of generality, a starting position for the investigation can be arbitrarily established with the Crank (Link 2) oriented at 60 degrees, as shown in Figure 3. A hybrid method using kinematic equations for velocity or acceleration in combination with graphical polygon constructions for velocity or acceleration developed in SolidWorks sketch mode can be used to analyze the starting position. Obviously, the same methodology can be applied to any other Crank position; however, to evaluate a complete cycle in this manner would be an arduous and time-consuming process. The Motion Study simulation tools within SolidWorks provide an alternative that continuously evaluates and reports parameters throughout the entire cycle. With the Crank in the starting position, parameter values obtained using both methods can be compared and assessed to evaluate the reliability of the CAD model simulation.

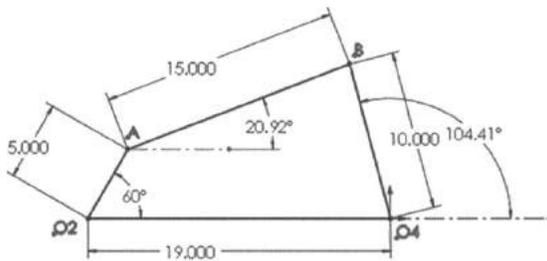


Figure 3. Mechanism starting position

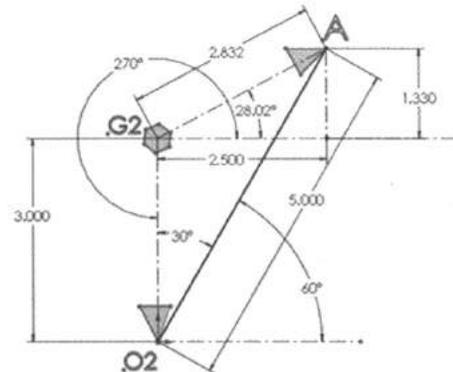


Figure 4. Crank center of mass

The mechanism being demonstrated is a single degree of freedom system; therefore, one coordinate is sufficient to associate position, angular velocity and angular acceleration at any instant in time. The center of mass of each link is required to calculate linear velocity and linear acceleration. Figures 4, 5 and 6 respectively show details for the center of mass of the moving links: Crank (Link 2), Coupler (Link 3) and Rocker (Link 4). Link 1 is fixed; hence, its center of mass information is not required. The  $P$  shown in Figure 5, is an external load. In these figures, the position vectors originate at the center of mass (hexagon) of each link and terminate at link connecting points. If vector methods are used, this method of locating the center of mass and connecting points is helpful when writing the equations of motion during rotation. These figures were drawn using the SolidWorks Sketch tools; their use simplifies determining the horizontal and vertical components of the position vectors.

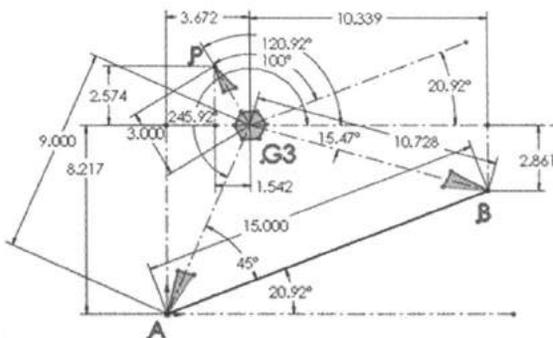


Figure 5. Coupler center of mass

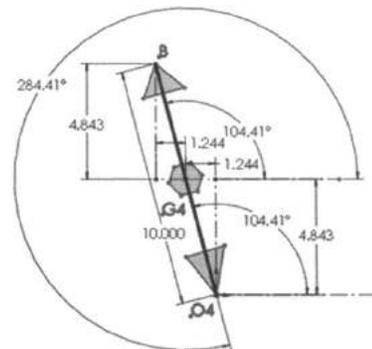


Figure 6. Rocker center of mass

At the initial time, with the Crank (Link 2) in the 60-degree starting position, the initial angular velocity is 1432.39 deg/s (25 rad/s) and the initial acceleration is -2291.83 deg/s<sup>2</sup> (-40 rad/s<sup>2</sup>). Using these parameters, the linear velocities and accelerations of key points, such as link connecting points, and the angular velocities and accelerations of each link can be determined. The acceleration polygons and center of mass accelerations for each link in the mechanism are shown in Figures 7, 8, 9 and 10.

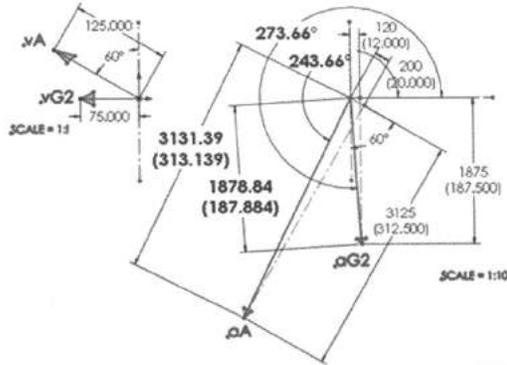


Figure 7. Crank velocity polygon and acceleration polygon



Figure 8. Rocker acceleration polygon for acceleration of the center of mass



Figure 9. Coupler velocity polygon and acceleration polygon



Figure 10. Coupler acceleration polygon for acceleration of the center of mass

Table 1 summarizes the key kinematic values computed by the combined method of analysis using kinematic equations with polygons sketched in SolidWorks. These quantities along with external load information provide the data necessary to study the kinetics of the mechanism.

Table 1. Summary of key kinematic values

	Angular Position (degrees) see Figure 6.	Angular Velocity (rad/s) & (deg/s)	Angular Acceleration (rad/s <sup>2</sup> ) & (deg/s <sup>2</sup> )	Acceleration of Center of Mass (in/s <sup>2</sup> @ θ deg)
<b>Crank</b>	60	25 (1432.40)	-40 (-2291.83)	1878.84@273.66
<b>Coupler</b>	20.92	-5.87 (-336.33)	120.9 (6927.06)	3646.6@226.51
<b>Rocker</b>	104.41	7.93 (454.36)	276.30 (15830.83)	1416.85@207.24

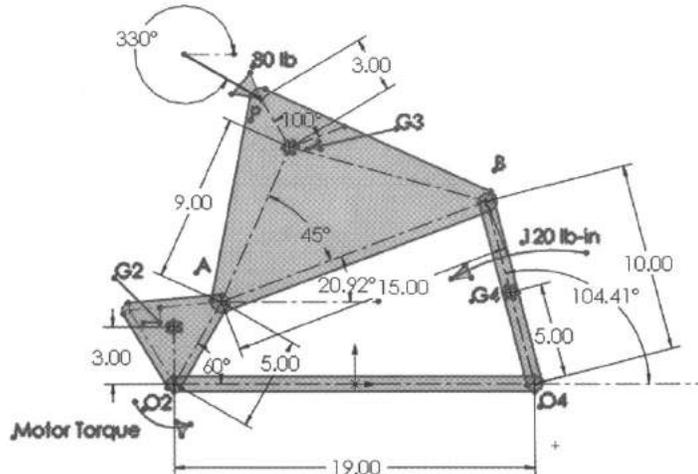
Negative values indicate clockwise direction.

#### 4. KINETIC STUDY OF THE SYNTHESIZED MECHANISM

A kinetic study of the mechanism involves the calculation of source and internal forces and torques. These forces, along with the external loads and torques, produce the motion characterized by the kinematic study. The values presented in Table 1 characterize the motion of the mechanism at one instant, the starting position. This information, along with the external loads, mass and mass moment of inertia ( $I_G$ ) of each moving link, at that same instant, is sufficient to find the other forces and torques necessary to satisfy the laws of motion at that instant. Table 2 provides the weight ( $W$ ) and mass moment of inertia about the center of mass of each moving link. The external loads at the starting position are provided in Figure 11.

**Table 2. Weight and mass moment of inertia of each moving link**

	Weight, $W$ (lb)	Mass Moment of Inertia about Center of Mass, $I_G$ (lb·in·sec <sup>2</sup> )
<b>Crank</b>	1.5	0.4
<b>Coupler</b>	7.7	1.5
<b>Rocker</b>	5.8	0.8



**Figure 11. External loads of 80 lb. force at  $P$  on the Coupler and 120 lb·in of torque on the Rocker; the source motor torque on the Crank is desired**

Newton's Laws of Motion are now applied to solve for the source motor torque applied to the Crank (Link 2) and the forces applied by each link on connecting links at the pin locations. This requires drawing free body diagrams of each moving link before applying the laws of motion. These diagrams are created in the CAD solid modeler and shown as Figures 12, 13 and 14.



$$\left(R_{43x}F_{43y} - R_{43y}F_{43x}\right) + \left(R_{23x}F_{32y} - R_{23y}F_{32x}\right) + \left(R_{P_x}F_{P_y} - R_{P_y}F_{P_x}\right) = I_{G_3}\alpha_3 \quad \text{Eqn. 6}$$

For the Rocker (Link 4):

$$F_{14x} - F_{43x} = m_4a_{G4x} \quad \text{Eqn. 7}$$

$$F_{14y} - F_{43y} = m_4a_{G4y} \quad \text{Eqn. 8}$$

$$\left(R_{14x}F_{14y} - R_{14y}F_{14x}\right) - \left(R_{34x}F_{43y} - R_{34y}F_{43x}\right) + T_4 = I_{G_4}\alpha_4 \quad \text{Eqn. 9}$$

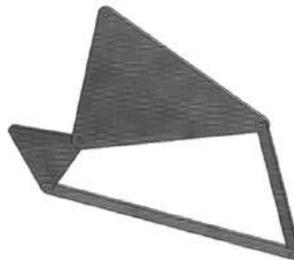
The resulting nine equations can be compared to those given in an example published by Norton in *Design of Machinery* on pages 592-595 (Norton, 2012). The results shown in Table 3 were obtained by solving these nine equations simultaneously using MATLAB (The MathWorks, Inc., 2020); they match those published by Norton. Using SolidWorks to create the free body diagrams minimizes the risk of errors, is generally faster than preparing hand drawn figures and generates detailed diagrams from which the parameter values required to solve the equations of motion are easily obtained.

**Table 3. Results of the solution of the nine kinetic equations for the unknown forces and torque**

$F_{12x} (lb)$	$F_{12y} (lb)$	$F_{32x} (lb)$	$F_{32y} (lb)$	$F_{43x} (lb)$	$F_{43y} (lb)$	$F_{14x} (lb)$	$F_{14y} (lb)$	$T_{12} (lb\cdot in)$
-117.55	-107.50	118.02	100.21	-1.32	87.45	-20.25	77.70	243.05

## 5. USING MOTION STUDY TOOLS FOR KINEMATIC AND KINETIC SIMULATION

The Motion Study tool within SolidWorks will now be used to repeat the kinematic and kinetic study. Thus far, not much attention has been paid to the actual size, shape or materials used for the links. The link length (between pin locations), mass, center of mass and mass moment of inertia values have all been assumed. A solid model will be created using these assumed values rather than by specifying a detailed geometry and material from which the values would then be determined. This is possible in SolidWorks using an over-ride feature that allows the designer to specify values for geometric and/or material dependent parameters such as mass and mass moment of inertia. It is recognized that for a final design, these properties must be derived for the actual final shape being used, and that this shape is also required to determine assembly interference avoidance and manufacturing processes; however, for this study (and most preliminary designs), the actual shape is not critical. Figure 15 shows a trimetric view of the solid models of the four links and their assembly. The model is approximate as it is based solely upon the link lengths between pins and the proper mates between links. Link 1 is fixed, to make the assembly a proper mechanism, and the Crank (Link 2) is positioned at 60 degrees (the start position).



**Figure 15. Trimetric view of the assembly of solid models of the four links**

The Motion Study tool in the SolidWorks assembly file is used to conduct kinematic and kinetic simulations. The tool features three levels of simulation: Animation, Basic Motion and Motion Analysis. The Motion Analysis simulation includes all the analysis and outcomes desired for this study. To run the simulation, a rotary motor is attached to the Crank (Link 2) and the motion expressions shown below are set up to provide the Crank the starting angular velocity of 25 rad/s and angular acceleration of -40 rad/s. The horizontal and vertical components of the 80 lb. external force applied at point *P* on the Coupler (Link 3) and 120 lb·in external torque on the Rocker (Link 4) are set up. These external forces and torque are assumed to be constant throughout the motion in magnitude and direction; although, they could be variable and set up as expressions if needed. The animation and plotting parameters are then set up.

$$\text{motor angular velocity} = 565.6961 * \sin(6.283185307 * \text{TIME} + 2.271547) + 1000 \text{ deg/s}$$

$$\text{motor angular acceleration} = 3554.373 * \cos(6.283185307 * \text{TIME} + 2.271547) \text{ deg/s}^2$$

The simulation provides visualization of the motion of the mechanism using animation and plots. For the rocker mechanism studied, continuous plots of the angular velocity and angular acceleration of the Coupler (Link 3), and the reaction force 1 and motor torque 2 on the Crank (Link 2) are shown for a duration of two seconds of time in Figures 16 through 19. The plots were created in the Results section of the Property Manager within the SolidWorks Motion Study tool. These are just a few of the plots that could be prepared since this, and similar information, can be extracted for any object, part or location in the solid model. The plots shown here confirm that the start time ( $t=0$ ) values, as shown in Table 1 or Table 3, are matched by the simulation. This study demonstrates the functionality of solid modeling and applicability of using a hybrid method of analysis where information from the solid model is combined with classic analysis techniques. In the real-world, simulation is used to minimize the potential for error, maximize efficiency, and provide improved design solutions through the iterative processes that are typical of design. Simulations provide better visualization and allow more iterations.

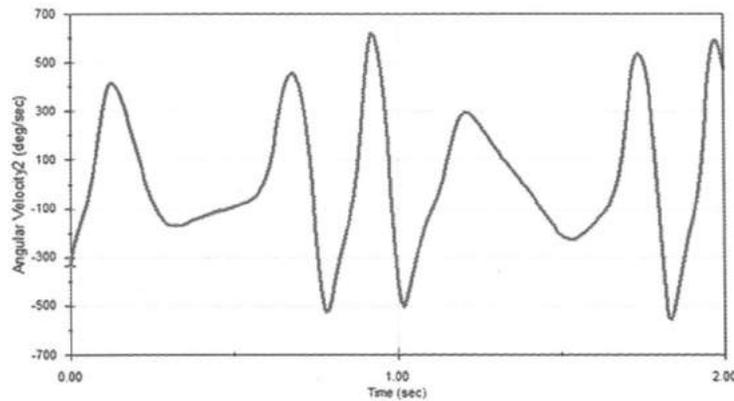


Figure 16. Angular velocity (deg/s) of the Coupler (Link 3) vs Time (sec).

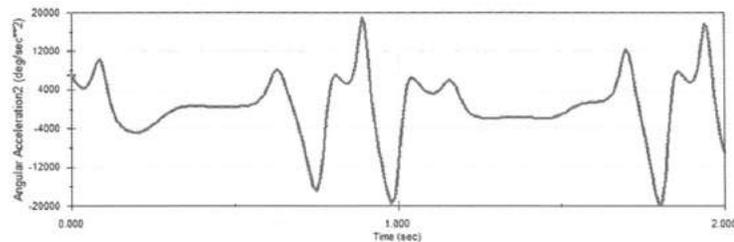
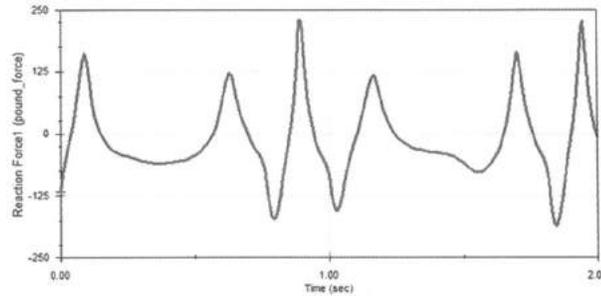
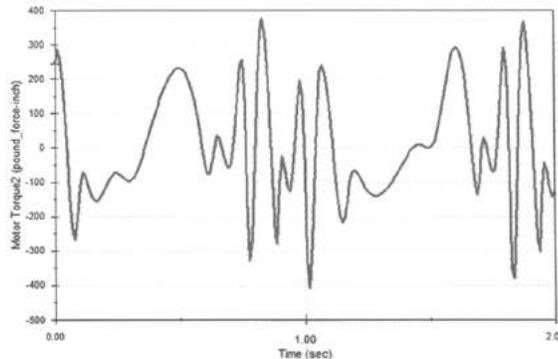


Figure 17. Angular acceleration (deg/s<sup>2</sup>) of the Coupler (Link 3) vs Time (sec).



**Figure 18. Horizontal force  $F_{12x}$  (lb) by Link 1 (Fixed) on the Crank (Link 2) at  $O_2$  vs Time (sec).**



**Figure 19. Motor torque (lb·in) on the Crank (Link 2) vs Time (sec).**

## 6. CONCLUSIONS

The practice of using a solid modeler simulation that is supported by an alternative means of analysis to establish the simulation accuracy and reliability has been presented through the study of a simple rocker mechanism. The ability to quickly solve advanced synthesis and analysis problems involved with mechanism design has been demonstrated, as was the ability to merge CAD sketches with traditional methods of analysis thus creating hybrid analysis method and an alternative means of checking the validity of the simulation results. While in school, engineering students learn how to combine classical methods of analysis with modern computing tools, such as CAD solid modelers, to work efficiently and effectively in today's exciting world of design.

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# A Finite Difference Solution for 1-D Soil Consolidation Using Excel

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**Abstract:** Terzaghi's one-dimensional (1-D) soil consolidation equation is solved using a finite difference (FD) method and Microsoft's Excel spreadsheet. Spreadsheets are inexpensive computational tools that are readily available to students and practicing engineers. They are relatively easy to use and, in many instances, have replaced calculators. Spreadsheets can perform the complex calculations associated with design problems in any engineering discipline. They are an ideal computational tool for engineering design work, an inherently iterative process, where strings of interrelated mathematical expressions are reevaluated every time a problem parameter, such as a length, is changed. For spreadsheet calculations, all the fundamental mathematical operations are available and most also include a suite of intrinsic functions accommodating operations involving logic, statistics, calendars, finances, etc. Of all the spreadsheet features available, the ability to create and run user developed programs may be the most overlooked but powerful resource. Using Microsoft's Visual Basic Applications (VBA) development tool in Excel, a user can write/run analysis routines of their own making within a spreadsheet. This powerful feature is demonstrated using the FD method and a 1-D soil consolidation problem.

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## 1. INTRODUCTION

Karl Terzaghi's theory for 1-D consolidation of a saturated, compressible soil was introduced in 1943 (Terzaghi, 1943). Today, soil consolidation solutions are well developed and often introduced in undergraduate civil engineering courses. The fundamentals required to understand FD methods are introduced in undergraduate calculus courses and were known to Euler as early as 1768 (O'Connor & Robertson, 1998). The first formal FD method of analysis is often attributed to a paper by Courant (Courant, Friedrichs, & Lewy, 1928) (Lax, 1967). As an analytical technique, finite differencing developed steadily throughout the twentieth century and was well positioned for computer adaptation as the digital age of computing was ushered in mid-20<sup>th</sup> century (Thomee, 2001). Today, FD solutions are the basis of many analysis programs in structures, fluids and heat transfer; often running in the background.

Spreadsheet programs, like Excel, are also an outcome of the digital computing age. These programs make quick work of repetitive computations and, in a business environment, allow calculations to be well documented in work notes, job folders, memos and reports. They are widely used in engineering practice and thus an important tool for engineering students to learn to use.

The spreadsheet platform, a two-dimensional grid of cells wherein numbers are entered and mathematical operations performed, is intuitive, open and easy to revise; it is ideal for creative problem solving (Wikipedia, 2020). The ease of use, experienced while in school, carries over into professional practice where spreadsheets are used for all manner of engineering analysis and design work because they are intuitive, open and easy to adjust (Gottfried, 2019). Any sequence of calculations doable on a handheld calculator, can be done just as fast in a spreadsheet; however, recalculating the sequence for a revision of one number involves only changing that number in a single spreadsheet cell (regardless of how many times

or other places it is referenced) and the entire calculation is instantly updated. Calculations that occur frequently in a workflow can be named, saved as macros and inserted using a user defined shortcut, such as CTRL+SHIFT+A. More extensive calculations can be programmed using VBA as functions or subroutines that are compiled and run outside of the spreadsheet cells. These programs can use values within spreadsheet cells as input parameters and arguments (Microsoft, 2019) (Carney, 2020) (Walkenbach, 2013). These programs are also nameable, can be used multiple times in a sheet or transported to new spreadsheets; they can be executed with a simple user defined shortcut.

## 2. BACKGROUND

Terzaghi's equation for 1-D soil consolidation is  $\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2}$  where  $u$  is excess pore pressure;  $t$  is time, measured from the time that  $u$  was generated, and  $z$  is length, in the vertical direction (the thickness of a soil layer);  $c_v$  is the coefficient of consolidation, a soil parameter with units of area per time (ft<sup>2</sup>/day) (Terzaghi, 1943). When loads are applied on the ground surface, stress throughout the underlying soil formation is increased to support the additional load. In layers of saturated, compressible soil the increase in stress is initially taken by the fluid (typically water) in the pore space as an excess pressure, or pressure that is in excess of the background (steady state) pore pressure. Over time the excess pore pressure dissipates (fluid in the pore space flows toward areas of lower energy) and the change in stress is slowly transferred to the solid phase of the soil. The development of Terzaghi's equation is outlined in introductory geotechnical engineering textbooks (Holtz & Kovacks, 2011). Solving the equation using FD is relatively straight forward as differencing equations are developed and substituted for each of the differential terms. Numerous references are available for the general FD procedure and applications specific to 1-D soil consolidation such as work published by Olson and Crank (Olson & Ladd, One-Dimensional Consolidation Problems, 1979) (Crank & Nicolson, 1947).

In the notes provided for an Advanced Soil Mechanics course taught by Dr. Lai at Chaoyang University of Technology, Dr. Olson offers a brief but well developed explanation of applying the FD method to solve 1-D consolidation problems (Olson, Application of Finite Difference Methods to the Solution of Consolidation Problems, 1989). The notes include an example that will be repeated here to demonstrate working a problem using a spreadsheet that many engineers would consider not suitable to work in a spreadsheet; maybe even impossible to work in a spreadsheet.

FD methods fall into three general categories that use forward differences, backward differences and central differences, respectively. The differencing equations (where differences in the values of a field variable,  $u$  for the consolidation problem, are evaluated at discrete locations) are used to approximate derivatives, such as  $\frac{du}{dt}$ . If, at a discrete location,  $u_i$  is the excess pore pressure at a particular time  $t$  and  $u_{i+1}$  is the excess pore pressure at a later time,  $t+\Delta t$ , then the first order forward difference approximation for  $\frac{du}{dt}$  is  $u'_i = \frac{u_{i+1}-u_i}{\Delta t}$ , similarly the first order backward difference for  $\frac{du}{dt}$  is  $u'_i = \frac{u_i-u_{i-1}}{\Delta t}$  where  $u_{i-1}$  is the excess pore pressure at  $t-\Delta t$ . The first order central difference for  $\frac{du}{dt}$  is  $u'_i = \frac{u_{i+1}-u_{i-1}}{2\Delta t}$ . Differencing equations can be written for changes in time ( $\Delta t$ ) or space ( $\Delta z$ ), and for any order of differential operation ( $\frac{du}{dz}$ ,  $\frac{\partial^2 u}{\partial z^2}$ , etc.). Higher order differencing equations are obtained for higher order differentials by repeated differencing operations. As an example, for  $\frac{\partial^2 u}{\partial z^2}$ , the second order forward difference is obtained by differencing each term in the first order difference equation:

$$u''_i = \frac{\left(\frac{u_{i+2}-u_{i+1}}{\Delta z}\right) - \left(\frac{u_{i+1}-u_i}{\Delta z}\right)}{\Delta z}$$

Values of the field variable at successive nodes, spaced at intervals of  $h$ , can be obtained using a Taylor series where  $u_{i+1} = u_i + \sum_{n=1}^{\infty} \frac{h^n}{n!} u_i^{(n)}$  (Hass, Heil, & Weir, 2018). When the series converges, accuracy

improves with the number of terms used. In the FD method, the series expression for each  $u_i$  is substituted into the differencing equations. Typically, using only the first term of the series provides sufficient accuracy. This results in a system of equations that is solved for the discrete  $u_i$  values.

The 1-D soil consolidation problem involves determining pore pressure in one spatial dimension, at discrete depths throughout the thickness of a soil layer, and in time. The problem seems well suited for a spreadsheet where rows would represent depths and columns a snapshot in time. Indeed, for certain situations, a spreadsheet solution structured in this manner is quite satisfactory. To start the analysis, the distribution of excess pore pressure ( $u_{e0}$ ) at uniform increments of depth, through the thickness of a soil layer, and at an initial time ( $t_0$ , usually when  $t=0$ ) is entered in the first column. These  $u_{e0}$  values are the initial conditions for the problem. Boundary conditions are then required. These conditions define the drainage behavior at the top and bottom of the soil layer; there are two possibilities: the drained condition, where the excess pore pressure is typically set to 0 for all time steps; and the undrained condition, where no flow occurs across the boundary. The undrained condition is modeled using a mirrored  $u$  value on the other side of the boundary. When the resulting system of equations can be solved explicitly, this is a very satisfactory set up. The differencing equations for  $u$ 's at the next time are written in the column next to the column of initial conditions and the solution is automatic (explicit); it is solved as the equations are entered. The entire column can be copied into neighboring columns for a solution that marches along in uniform increments of time.

In a spreadsheet, the explicit solution is easy to program; however, there is a limitation, the solution is only stable for relatively short increments of time. For a typical problem, consolidation (the dissipation of excess pore pressure) can involve tens, if not hundreds of years. When the maximum stable time step is measured in days or even hours, arriving at meaningful data (20, 50 or 80 percent dissipation) may involve thousands of columns and reams of paper (if carelessly sent to a printer). An explicit method of analysis using the first forward difference equation for the first derivative of  $u$  in time ( $t$ ) and the second central difference equation for the second derivative of  $u$  in depth ( $z$ ) will be demonstrated. Of course, there are other solutions, but they are not as straight forward to program in a spreadsheet.

An attractive implicit FD method, the Crank-Nicolson method, will also be demonstrated. In this method the  $\Delta t$  can be variable between time steps and rather large without sacrificing accuracy, but the differencing equations used are not explicit, they must be solved simultaneously. An iterative method known as Gauss-Seidel, Seidel's method, the Liebmann method, or the method of successive displacement is used in the example problem (Wikipedia, 2020). The solver is programmed using VBA and is run from a cell in the Excel spreadsheet. It does all the calculations in a compiled program and solves the system of equations without doing any operations in cells within the spreadsheet.

The focus of a soil consolidation analysis is the compressible soil that exists at some depth below the surface. It is this soil, and the water in its pore space, that results in consolidation. When a load is applied on the ground surface, that load is supported by a change in the vertical stress at points located throughout the subsurface soil profile. In a 1-D analysis, a uniform load ( $q$ ) is applied over an area that is large compared to the average depth and thickness of the underlying compressible layer. The change in stress ( $\Delta\sigma_v$ ), at all depths, is then equal to  $q$ . Initially, the  $\Delta\sigma_v$  in the compressible soil layer is carried by the pore fluid as  $u_{e0}$ , the initial excess pore pressure. The excess pore pressure immediately begins to dissipate as pore fluid drains toward a drainage boundary. The percentage of  $u_{e0}$  dissipated at any  $t$  is reported as  $U$  for that  $t$ . Either the top, the bottom, or both soil layer boundaries may allow drainage. The single drained case is when only one of the soil layer boundaries allows drainage; in this case, the length of the longest drain path ( $H$ ) is the thickness of the layer. In the double drained case, where both surfaces allow drainage,  $H$  is half the layer thickness. The double drained case can be modeled as a single drained layer that is half as thick as the actual soil layer thickness. The coefficient of consolidation,  $c_v$ , is a property of the soil that describes the rate at which the dissipation of  $u_{e0}$  takes place.

### 3. EXPLICIT SOLUTION EXAMPLE

In the explicit solution, the differential equation to solve is  $\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2}$ . The first forward difference equation is substituted for  $\frac{\partial u}{\partial t}$  and the second central difference equation for  $\frac{\partial^2 u}{\partial z^2}$  to get  $\frac{u_{i,j+1} - u_{i,j}}{\Delta t} = c_v \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{\Delta z^2}$  where  $i$  is the index for  $z$  and  $j$  is for  $t$ . The equation only has one  $j+1$  term; therefore, it can be isolated on the left side and calculated; thus, the explicit nature of this method. At a drainage boundary  $u_{i,j+1}$  is known and specified. At an impermeable boundary, the  $u_{i+1,j}$  term is a mirror of, and therefore equal to, the  $u_{i-1,j}$  term. The equation to solve (code into the spreadsheet) is

$$u_{i,t+1} = u_{i,j} + \frac{c_v \Delta t}{\Delta z^2} [u_{i-1,j} - 2u_{i,j} + u_{i+1,j}]$$

which in terms of  $z$  and  $t$  is

$$u_{z,t+\Delta t} = u_{z,t} + \frac{c_v \Delta t}{\Delta z^2} [u_{z-\Delta z,t} - 2u_{z,t} + u_{z+\Delta z,t}].$$

As shown here,  $\Delta z$  is constant, meaning the discrete points where  $u_e$  is evaluated are uniformly spaced throughout the depth of the soil layer;  $\Delta t$  is also usually constant for each time step, but that is not a necessary condition. The  $\frac{c_v \Delta t}{\Delta z^2}$  term is often replaced by a coefficient  $\alpha$ , notice that it involves properties of the soil, the  $z$  spacing and the time increment. For the solution to be stable and meaningful,  $0 < \alpha \leq 0.5$ . The  $\Delta z$  and  $\Delta t$  parameters are adjusted to insure this condition.

For this example,  $u_{e0}$  is set at 100 and  $\alpha$  is 0.25. A single drained layer of soil is modeled. The drainage boundary is at the top (the Drained node  $u_e$  is always zero) and the impermeable boundary is at the bottom (node 6 is mirrored for the would-be node 8 at the Imperm. node);  $u_e$  is calculated at five equally spaced intervals through the depth of the layer and at each boundary. The cell equations used and the calculated values for the first-time step are shown in Figure 1. The cell equations are then copied into the next eight columns to perform the calculations shown in Figure 2. The calculation process is simple.

	A	B	C	D	E	F	G
1	1-D Consolidation		Explicit FD Method				
2	$\alpha =$	0.25	$\alpha = c_v \Delta t / \Delta z^2$	$c_v$	$\Delta z$	$\Delta t$	
3	$0.3 \leq c_v \leq 35$ ft <sup>2</sup> /day			ft <sup>2</sup> /day	ft	day	
4	For the $\alpha$ shown:				10	5	0.625
6	z Node	$u_{e0}$	$u_e(t1)$	Cell equations:			
7	Drained	0	0	=+B7			
8	2	100	75	=B8+\$B\$4*(B7-2*B8+B9)			
9	3	100	100	=B9+\$B\$4*(B8-2*B9+B10)			
10	4	100	100	=B10+\$B\$4*(B9-2*B10+B11)			
11	5	100	100	=B11+\$B\$4*(B10-2*B11+B12)			
12	6	100	100	=B12+\$B\$4*(B11-2*B12+B13)			
13	Imperm.	100	100	=B13+\$B\$4*(B12-2*B13+B12)			

Figure 1. Initial conditions and spreadsheet equations used to calculate  $u_e$  for the first-time step.

	A	B	C	D	E	F	G	H	I	J	K
1	1-D Consolidation		Explicit FD Method								
2	$\alpha =$	0.25	$\alpha = c_v \Delta t / \Delta z^2$	$c_v$	$\Delta z$	$\Delta t$					
3	$0.3 \leq c_v \leq 35$ ft <sup>2</sup> /day			ft <sup>2</sup> /day	ft	day					
4	For the $\alpha$ shown:				10	5	0.625				
6	z Node	$u_{e0}$	$u_e(t1)$	$u_e(t2)$	$u_e(t3)$	$u_e(t4)$	$u_e(t5)$	$u_e(t6)$	$u_e(t7)$	$u_e(t8)$	$u_e(t9)$
7	Drained	0	0	0	0	0	0	0	0	0	0
8	2	100	75.000	62.500	54.688	49.219	45.117	41.895	39.276	37.094	35.239
9	3	100	100.000	93.750	87.500	82.031	77.344	73.315	69.824	66.769	64.072
10	4	100	100.000	100.000	98.438	96.094	93.457	90.771	88.153	85.654	83.293
11	5	100	100.000	100.000	100.000	99.609	98.828	97.754	96.484	95.094	93.636
12	6	100	100.000	100.000	100.000	100.000	99.902	99.658	99.255	98.700	98.006
13	Imperm.	100	100.000	100.000	100.000	100.000	100.000	99.951	99.805	99.530	99.115

Figure 2. Calculation of  $u_e$  for the first nine-time steps.

#### 4. IMPLICIT CRANK-NICOLSON SOLUTION EXAMPLE

Solving Terzaghi's 1-D consolidation equation,  $\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2}$ , using the Crank-Nicolson method is accomplished using a first order forward differencing equation for  $\frac{\partial u}{\partial t}$  and an average of the second order central difference equation for times  $t_j$  and  $t_{j+1}$  for the  $\frac{\partial^2 u}{\partial z^2}$  term as shown below.

$$\frac{u_{i,j+1} - u_{i,j}}{\Delta t} = \frac{c_v}{2\Delta z^2} (u_{i-1,j} - 2u_{i,j} + u_{i+1,j} + u_{i-1,j+1} - 2u_{i,j} + u_{i+1,j+1})$$

When the equation is rearranged and  $\alpha$  is substituted for  $\frac{c_v \Delta t}{\Delta z^2}$ , the following expression is obtained.

$$-u_{i-1,j+1} + \frac{2(1+\alpha)}{\alpha} u_{i,j+1} - u_{i+1,j+1} = u_{i-1,j} + \frac{2(1-\alpha)}{\alpha} u_{i,j} + u_{i+1,j}$$

All of the terms on the right hand side are at the  $j$  time, thus they are known. The right hand side is a constant,  $C_{i,\Delta t}$ . Now, define  $D_{i,\Delta t} = \frac{2}{\alpha} + 2$  then  $u_{i,j+1} = \frac{C_{i,\Delta t} + u_{i-1,j+1} + u_{i+1,j}}{D_{i,\Delta t}}$ . This results in a system of  $N$  equations for the  $u_i$  that are to be determined at any given time step.

Begin the spreadsheet analysis by building a template for the soil properties and problem configuration values. The template for the example problem is shown as Figure 3. The FD equations and a Gauss-Seidel equation solver are then programed; see the VBA code shown in Figure 5. After entering a  $\Delta t$ , the  $u_i$  for that time step are calculated by running the VBA code from within that cell. The VBA routine looks for the soil properties and other analysis parameters *in the template locations shown* for every  $\Delta t$  specified and writes the calculated  $\alpha$ ,  $U$  and  $u_i$  below the  $\Delta t$ . Figure 4 shows the results for nine time steps. The first three are the same as those used in the previous explicit analysis; the fourth  $\Delta t$  is calculated to match the  $t$  of the ninth time step in the explicit analysis. The results shown in Figure 4 compare well with those in Figure 2. Notice,  $\alpha$  can be much larger than  $\frac{1}{2}$ . The differencing equations could be entered in individual cells and solved within Excel; however, it would require several columns for each  $\Delta t$ . The VBA program does all the calculations and no cells are used.

	A	B	C	D	E	F	G	H	I	J	K
1	1-D Consolidation			Crank-Nicolson Finite Difference Method w/Gauss-Seidel Solver							GS_1
2	$c_v =$	10	ft <sup>2</sup> /day	Coefficient of Consolidation for the layer of compressible soil.							
3	$\Delta z =$	5	ft	Node spacing							
4	$N =$	7		Number of nodes; node 1 is the drainage boundary,							
5		$\alpha = c_v \Delta t / \Delta z^2$		node N is the impermeable boundary.							
6		$\Delta t =$	0.625	To analyze the example problem, start by entering soil parameters and configuration values: $c_v$ , $\Delta z$ , $N$ and the $u_{e0}$ . Then enter the first $\Delta t$ and, with that cell active (cell with the $\Delta t$ value highlighted), execute the GS_1 VBA program. NOTE: GS_1 expects to find values for $c_v$ , $\Delta z$ , $N$ , the $u_{e0}$ vector, and the first $\Delta t$ in the locations shown. Additional $\Delta t$ 's are placed on the same line in consecutive columns. Executing GS_1 writes $\alpha$ , $t$ , $U$ and the vector of $u$ 's for $t$ below each $\Delta t$ .							
7		$\alpha =$									
8	$t =$	0									
9	$U =$	0									
10	Node	$u_{e0}$	$u_e(0)$								
11	1	0		<b>Crank-Nicolson formulation:</b>							
12	2	100									
13	3	100									
14	4	100		$C_{i,\Delta t} = u_{i-1,t} + \left( \frac{2(\Delta z)^2}{C_v \Delta t} - 2 \right) u_{i,t} + u_{i+1,t} \quad D_{i,\Delta t} = \frac{2(\Delta z)^2}{C_v \Delta t} + 2$							
15	5	100									
16	6	100		$u_{i,t+\Delta t} = \frac{C_{i,\Delta t} + u_{i-1,t+\Delta t} + u_{i+1,t}}{D_{i,\Delta t}}$							
17	7	100									

Figure 3. The example problem soil properties and parameters set up and ready to run GS\_1.

	A	B	C	D	E	F	G	H	I	J	K
1	1-D Consolidation			Crank-Nicolson Finite Difference Method w/Gauss-Seidel Solver							GS_1
2	$c_v =$	10	ft <sup>2</sup> /day	Coefficient of Consolidation for the layer of compressible soil.							
3	$\Delta z =$	5	ft	Node spacing							
4	$N =$	7		Number of nodes; node 1 is the drainage boundary,							
5		$\alpha = c_v \Delta t / \Delta z^2$		node N is the impermeable boundary.							
6	$\Delta t =$	0.625	0.625	0.625	3.75	4.375	10	20	35	50	
7	$\alpha =$	0.25	0.25	0.25	1.5	1.75	4	8	14	20	
8	$t =$	0	0.625	1.25	1.875	5.625	10	20	40	75	125
9	$U =$	0	0.040863	0.074227	0.102718	0.22892	0.327171	0.494904	0.710516	0.897861	0.980382
10	Node	$u_{e0}$	ue(0.63)	ue(1.25)	ue(1.88)	ue(5.63)	ue(10)	ue(20)	ue(40)	ue(75)	ue(125)
11	1	0	0	0	0	0	0	0	0	0	0
12	2	100	79.7959	67.00685	58.35598	34.19339	27.56591	18.56262	11.08592	3.636211	0.90462
13	3	100	97.95897	93.33403	88.18449	64.69736	51.24678	36.50845	20.91925	7.460542	1.347743
14	4	100	99.79382	98.98991	97.48793	84.41011	70.34656	51.66596	29.64333	10.47116	1.992997
15	5	100	99.97917	99.86392	99.55733	93.91964	83.57661	63.3526	36.33228	12.77765	2.4942
16	6	100	99.99788	99.98258	99.92927	97.6095	90.80537	70.92819	40.37683	14.36317	2.6876
17	7	100	99.99957	99.99583	99.97988	98.52742	93.02949	73.56944	41.71746	14.93592	2.725772

Figure 4. Excess pore pressure values computed at nine instances in time and over 98% of consolidation

<pre> Sub GS_1() ' 'GS_1 Macro Gauss-Seidel ver 1 ' 'This macro uses delta t as the active cell!  Dim N As Integer, CV As Single, dz As Single, _ t As Single, dt As Single, D As Single, alpha As _ Single, alpha2 As Single, C() As Single, DIFF As _ Single, CK As Single, ut() As Single, udt() As _ Single, U0 As Single, U As Single, r As Integer  'Set Initial Conditions N = Range("B4").Value CV = Range("B2").Value dz = Range("B3").Value dt = ActiveCell.Value alpha = CV * dt / dz ^ 2 alpha2 = (1 / (alpha / 2)) ActiveCell.Offset(1, 0).Value = alpha t = ActiveCell.Offset(2, -1).Value + _ ActiveCell.Value ActiveCell.Offset(2, 0).Value = t  ReDim ut(N) ReDim udt(N) ReDim C(N)  CK = 0.002 U0 = 0 U = 0 C(1) = 1  ut(1) = ActiveCell.Offset(5, -1).Value For r = 2 To N     ut(r) = ActiveCell.Offset(4 + r, -1).Value     U0 = U0 + dz * (Range("B" &amp; Rows(10 + _ r - 1).Row) + Range("B" &amp; Rows(10 + r). _ Row)) / 2         </pre>	<pre> Next r For r = 2 To N - 1     C(r) = ut(r - 1) + (alpha2 - 2) * ut(r) + ut(r + 1) Next r C(N) = 2 * ut(N - 1) + (alpha2 - 2) * ut(N) D = alpha2 + 2 udt(1) = ut(1) GoTo 2  1 For r = 1 To N     ut(r) = udt(r) Next r C(1) = C(1) + 1  2 DIFF = 0 For r = 2 To N - 1     udt(r) = (C(r) + udt(r - 1) + ut(r + 1)) / D     DIFF = DIFF + ut(r) - udt(r) Next r udt(N) = (C(N) + 2 * ut(N - 1)) / D DIFF = DIFF + ut(N) - udt(N)  If C(1) &gt; 100 Then GoTo 4 If DIFF &gt; CK Then GoTo 1  3 For r = 2 To N     U = U + dz * (udt(r - 1) + udt(r)) / 2 Next r U = 1 - U / U0 GoTo 5  4 U = 999  5 For r = 1 To N     ActiveCell.Offset(4 + r, 0).Value = udt(r) Next r ActiveCell.Offset(3, 0).Value = U  End Sub         </pre>
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Figure 5. VBA code for the GS\_1 subroutine used in the Crank-Nicolson example.

## 5. CONCLUSION

The explicit method is easy to program in a spreadsheet; however, the maximum  $\Delta t$  that can be used is limited by stability;  $\alpha$  must be less than  $\frac{1}{2}$ . Often this results in a relatively small  $\Delta t$ , when compared to the time required for a high percentage of consolidation,  $U$  (the dissipation of excess pore pressure). This results in having to compute  $u_i$  values at numerous time steps (and numerous columns of data). The implicit routine can be used with large  $\Delta t$ 's and still achieve good accuracy. Thus, the effort required to determine a high percentage of consolidation requires far fewer time steps (columns). In the explicit analysis example, the nine-time steps shown resulted in approximately 29% consolidation at  $t = 5.625$  days. For the same  $t$ , the implicit method of analysis results in  $U$ 's of 24.456%, 22.692%, 22.640% and 22.601% and 22.561% for analyses using one, two, three, four, and nine-time steps, respectively; a uniform, but different,  $\Delta t$  was used in each analysis. The iterative computations required to solve the implicit method for numerous time steps in a spreadsheet would be difficult and time consuming to program in individual spreadsheet cells. However, by employing a VBA program, where *do loops* are available, the computations are easily accomplished through a single cell. A second-year engineering student should be able to create a similar code. Solving the consolidation problem presented here is interesting, but not the only goal of the paper. Encouraging students, practicing engineers and scientists to be creative, more productive and versatile by exploiting VBA development tools, that are probably already on their computer, is also a goal. Using VBA, anything that can be programmed can be worked in a spreadsheet. Calculations requiring a *do loop* are particularly troublesome in spreadsheet cells, but no trouble at all when that part of the calculation is carried out using a VBA subroutine!

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## Consumer Choice AHP Using Standard Open Source Tools

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**Abstract:** The Analytic Hierarchy Process (AHP) is an approach to multi-criteria decision analysis developed by Dr. Thomas Saaty et al. in the 1970's. The open source Python module `pyanp` is a library that can read in AHP/ANP models in various formats and perform the standard AHP/ANP theoretic calculations. Another open source library for performing AHP/ANP related calculations is `anpjs`, this one is written in JavaScript. In this research we extend both `pyanp` and `anpjs` to use Likert-type verbal votes for AHP pairwise comparison. We use a specially formatted Google Forms questionnaire to solicit participant pairwise preferences using our Likert-type scale, and tie that output to a Google sheet. We created Python and JavaScript libraries to convert the verbal votes into a standard numeric pairwise comparison matrix and sent that information on to the `pyanp` and `anpjs` libraries for use with calculations. We designed an AHP tree model for consumer choice of cell phones and created expert ratings for our cell phone choices with respect to the bottom level criteria of our model. We used that AHP tree model to design our Google Forms questionnaire so that the resulting spreadsheet could be parsed by `pyanp` and `anpjs` for analysis. Participants in the Google Forms questionnaire are dropped into a results mini application where they can explore how their preferences are shaped by the numerical meaning of the Likert voting scale. Additionally, we designed a Jupyter notebook for analyzing the results of all participants in this questionnaire using `pyanp` and `matplotlib`.

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### 1. INTRODUCTION

In today's world, for every consumer purchase there are a multitude of purchasing options. How can a consumer navigate through these to find the option that best aligns with their wants and needs? Many of the outlets that purport to help consumers do this are actually steering them towards a particular item that may or may not align with the consumer's needs; instead it aligns with the outlet's desires. For instance, a simple Google search always shows the ads first, before the organic search results. Another simple example is that every online purchasing site will steer you towards **at least one product**. What if all of the products they offer are poorly aligned with your needs? That concept does not exist in their searching system. There is no visibility for the consumer about how well something matches their needs.

Another consideration is that consumers actually have competing wants and needs. For instance, they want the best possible cell phone and it has to be cheap. When wants and needs are conflicting, which one wins? Typically, neither side wins, some side get more weight than the others. How can a consumer see how their best aligned choice changes as a factor becomes more and more important? Continuing with the cell phone choice example, how does the best aligned phone change as cheapness becomes more and more important?

The Analytic Hierarchy Process (AHP) is an approach to multi-criteria decision making that allows for these kinds of analyses. With a well-constructed AHP model, experts can evaluate the options using a hard and fast measuring system; while consumers can describe their conceptual preferences using pairwise comparisons. With the addition of Likert-type verbal pairwise voting from (Adams, 2016) consumers do not need any training in answering AHP questions to provide their preferential information. Consumers can then see how their preferences affect the possible best choice, and even see if any choices measure up to a minimal level of alignment.

## 2. MATHEMATICAL OVERVIEW

The Analytic Hierarchy Process (AHP) and its generalization, the Analytic Network Process (ANP) were developed by Dr. Thomas Saaty et al starting in the 1970's. In (Saaty 1990) the author lays out the standard notations and mathematical theory of the field. AHP theory helps people decide among many alternative choices by breaking up the bigger choice into many smaller decisions, and then using mathematical tools to synthesize those smaller decisions into the ultimate large decision. The items we are trying to choose between are called the alternatives. General AHP theory uses a hierarchy of criteria to break down the decision into smaller pieces. Our usage of AHP is limited to using trees for AHP modeling, instead of the more general hierarchies. By limiting ourselves to trees, the design and structure of the problem is simpler and easier for others to make use of and expand upon. Using AHP trees to model a decision requires the following pieces of information:

1. There is a tree of nodes, aka criteria. A tree is a directed graph where there is a single root node (a node with no parents) and all the other nodes have exactly one parent node.
2. The alternatives: these are the items we are ultimately choosing between. In our AHP tree setting every bottom level criterion is connected to every alternative.
3. For each parent criterion in the tree, we need a priority vector for how important the children criteria are with respect to the parent. This priority vector is called the local priority vector. In AHP theory this priority vector is typically found by pairwise comparing the children and then using the largest eigenvector method to derive a priority vector from the pairwise comparison matrix.
4. For each bottom level criterion, we rate (give a score between 0 and 1) each of the alternatives.
5. We use the local priority vectors to derive the weights for all of the bottom level criterion (by multiplying the bottom level node's weight by the weight of every parent) and then use those weights to take the weighted average of the ratings scores of the alternatives. This synthesis gives us the final scores of the alternatives.

## 3. PAIRWISE COMPARISONS AND THE LARGEST EIGENVECTOR METHOD

In (Saaty 1990) the process of performing pairwise comparisons is described as well as the method of using the largest eigenvector to derive a priority vector from those comparisons. Additionally, in (Saaty 2003) the reasoning behind the choice for the largest (principal) eigenvector is discussed. Let us look briefly at that method. Assume we have 3 criteria A1, A2, A3 underneath a parent criteria A. We need a priority vector for those children, but we cannot a priori define it. However, we may be able to describe, in a pairwise fashion, which child is better and by how much, with respect to the parent criterion A. Please note, the question being asked at each comparison is: "with respect to criterion A, which child is better and by how much". E.g. we may have the following pairwise data:

- with respect to A, criterion A1 is 2 times better than criterion A2, and
- with respect to A, criterion A2 is 3 times better than criterion A3, and
- with respect to A, criterion A1 is 5 times better than criterion A3

Notice that A1 is 2x better than A2 and A2 is 3x better than A3; if transitivity held then we could conclude that A1 is 6x better than A3. However, we are allowed to break transitivity in pairwise comparisons. In fact, breaking transitivity allows the pairwise comparison process to better handle real world situations. Please see (Saaty, Vargas 1984) for a discussion around inconsistency and its usefulness.

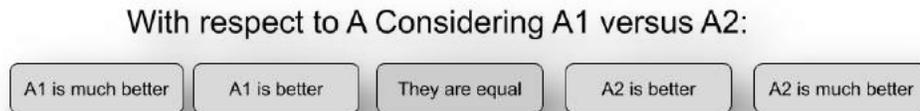
These pairwise comparisons can be converted into the following matrix:

$$\begin{bmatrix} 1 & 2 & 5 \\ 1/2 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix}$$

where the value in row  $R$  and column  $C$  tells us how the pairwise comparison of criterion  $R$  compared to criterion  $C$ . Since any criterion is equal to itself, that explains the 1's down the diagonal. The reciprocals are easily seen by example; A1 is twice as good as A2, thus A2 is half as good as A1. If we calculate the largest eigenvector and normalize it (so that its values add up to one) we get the following while rounding to 2 decimal places: [0.58, 0.32, 0.11]. Those values are the local priorities of A1, A2, and A3 with respect to A.

#### 4. SYMBOLIC PAIRWISE COMPARISONS AND LIKERT-TYPE SCALES

As part of the work in (Adams 2016) the author used symbolic pairwise comparisons to solicit feedback from participants with no knowledge of AHP. In particular they used a Likert-type 5-point voting system, like:



There are 5 possible votes, and in (Adams 2016) they convert those votes to numeric values by defining the numeric value of Better and Much Better. Using this methodology, we can answer each pairwise comparison verbally and have those votes converted to numerical votes to fill in the pairwise comparison matrix (and ultimately get the priority vector).

#### 5. MOTIVATING EXAMPLE, CONSUMER CELL PHONE CHOICE

In this work we use the tools defined above to enable consumer choice between different cell phone options. We do this by:

1. Creating an AHP tree that breaks up the decision into smaller components.
2. The bottom level criteria should be sufficiently well defined that an expert can rate each cell phone with respect to that criterion easily.
3. We choose the phones we are going to decide between.
4. Our expert evaluates each phone on the bottom level criteria.
5. Our users will pairwise compare the criteria.

Our AHP tree is:

- **Goal:** decide the best aligned phone for a participant
  - **Cost:** which phone does better with respect to cost?
  - **Style:** from a purely aesthetic perspective, which phone is better?
  - **Functionality:** this node breaks down into differing measures of functionality
    - **Photography:** which phone is better for photography?
    - **Gaming:** for gaming purposes, which phone is better?
    - **Storage:** for onboard storage, which phone is better?

Notice that Functionality breaks up into Photography, Gaming, and Storage. We do not evaluate the phones on Functionality directly, rather we evaluate them on the children: Photography, Gaming, and Storage. We could have broken Photography into other sub-criteria like Low Light, Sport, Pixel Count, etc. For the purposes of demonstrating the methodology we believe the above is sufficient to demonstrate the idea and utility.

The phones we use for the research are Samsung Galaxy S8, S10, S20, Google Pixel 4, iPhone X, iPhone 11. We could, of course, have included many more phones, however we believed those phones to be sufficient for demonstrating the usefulness of this methodology.

## 6. EXPERT RATINGS OF THE PHONE ON THE CRITERIA

Each of the lowest level criterion (in our case, cost, style, photography, gaming, and storage) had to be evaluated for each device. These evaluations were translated to a rating value between 0 and 1 (where 0 is the worst and 1 is the best) that was used in the calculations.

For our example, as much as possible, the scores were tied to some objective criteria. Cost and storage have values associated with them that could be directly used to calculate a rating value. However, simply dividing by the maximum score is often not useful for this process. In the case of storage, the larger the value, the better, but in the case of cost, the opposite is true. Additionally, the utility of the increase for many variables does not scale linearly. Four additional gigabytes of storage may be very useful if you currently have 4 gigabytes of storage, but less so if you already have 256 gigabytes of storage. Therefore, we often use a selection of nonlinear functions to take the data and convert it to appropriate values. Both the reciprocal and logarithm functions were used to scale the cost values for the functions and logarithm and scaling by a multiple to turn the highest value to 1 was used for the storage values.

For criteria that were more subjective, such as style, a subject matter expert or team of subject matter experts will typically rank the different products. Once that is done, one reasonable process is to calculate the reciprocals of the rank to give the best product a value of 1 and lower values for lower ranking products. For our example, reciprocals were then transformed slightly to increase the gaps between the values allowing increased differentiation between the products, while keeping the rating values in the required 0 to 1 interval.

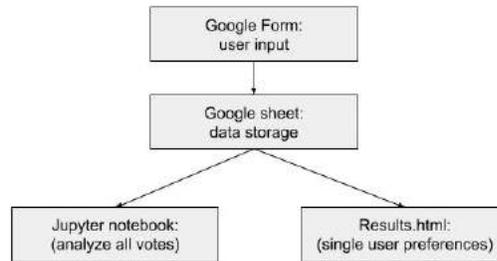
When the rating values of all the criteria are determined, the values were finally reviewed and loaded into the appropriate row in the Google sheet.

## 7. THE OPEN SOURCE TECHNOLOGY STACK

In this project we make use of several open source technologies to enable a simple online webform for participant pairwise voting, while allowing users to see their resulting preferences, and allowing us to do detailed analyses of group preferences. The main tools used are:

1. Google Forms for soliciting the pairwise comparisons for a particular participant.
2. Google Sheets for storing the votes. We can easily access Google Sheets using standard libraries available across many languages.
3. JavaScript for reporting back the result alternative preferences. We make use of the following open source libraries:
  - a. `anjjs`: this library performs the AHP theoretic calculations (Adams, 2020)
  - b. `plotly`: an open source library for developing interactive plots in many languages.
4. Python and Jupyter: we use these tools for analyzing the results of all participants in our AHP model. Jupyter provides an interactive environment for analyzing data and can be tied to many different backend languages (Kluyver, et al, 2016). For visualizations we use `matplotlib` (Hunter 2007). For connecting to our Google sheet and AHP theoretic calculations we used `pyanp` (Adams,

Rokou, 2020). Matplotlib works very well with publishing Jupyter notebooks online, for example via github. Our example results can be found in the Analysis.ipynb file in (Adams, Stryker, 2020) The following diagram shows the flow of information across these tools.



## 8. PROGRAMMING WORK REQUIRED FOR THE PROJECT

To tie these various components together there was some programming required. The anpjs library (Adams, 2020) required some added functionality, we needed to design and implement the results.html JavaScript application as well as the Analysis.ipynb Jupyter notebook (Adams, Stryker 2020). In addition, we had to design the Google Forms questionnaire so that pyanp and anpjs could read the resulting Google sheet. The anpjs library needed the ability to read in votes such as “A is much better than B” and convert those into a pairwise comparison matrix, given known values of the meaning of “better” and “much better”.

We designed the results.html JavaScript application using anpjs to load the data and plotly for visualization of the results. The anpjs library only handles single user votes at the time of this research project, so we needed to read in one user’s votes and load them into anpjs. We achieved this by reading directly from the Google sheet feed and parsing that json feed into a simple JavaScript matrix.

The Analysis.ipynb was designed to directly use pyanp for AHP theoretic calculations and matplotlib for visualizations. The two main difficulties were getting the Google sheet data loaded and parsing the verbal votes into numeric votes. We solved the Google sheet problem by using the requests library and getting the csv from our Google sheet via the feed mechanism. In order to convert verbal votes into numeric ones, we created a function to perform this operation column by column and placed it in the helpers.py found in (Adams, Stryker, 2020).

The Google form was designed with questions and responses that could be directly parsed by the already existing pyanp system for parsing Likert-type scales. Essentially this means:

1. The questions should be of the form A vs B for top level criteria and A vs B wrt C for others, where A is the name of one criterion and B is the name of another and C is the name of the parent node, if applicable. The names of the criteria cannot have the word “vs” or “wrt” in them, as we use that keyword for parsing the question context.
2. The results must be of the following form:
  - a. A is much better
  - b. A is better
  - c. They are basically equal
  - d. Other cases are handled by swapping A and B
3. There is some flexibility with the wording, better can be replaced with “more import” for instance and the word “basically” can be omitted from the equals case.
4. We tied the output of the Google form to a Google sheet.

5. We made that Google sheet public and created a link for sharing the sheet.
6. We use that sharing link for loading the Google sheet in both the results.html and the Analysis.ipynb of (Adams, Stryker, 2020).

## 9. RESULTS

Users can easily take part in our cell phone choice model by going to <https://forms.gle/D9Ach1LR9LZhcUgf9> and filling in their own preferences. At the end of the process they we present them with a link that takes them to the results.html JavaScript application, which defaults to showing the most recent participant. We can go directly to that page by visiting the site <https://bamath.org/consumerAHP/results.html> which presents a page resembling:

### Cell Phone Choice Results

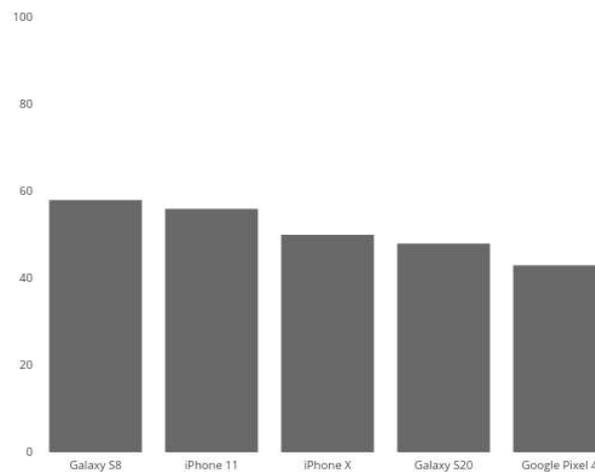
Here are the results for the cell phone consumer choice model for the most recent participants.

For Voter:

AHP Better Value:

AHP Much Better Value:

Best Cell Phone Scores



In this user interface the user can:

1. Choose the participant they are seeing the priorities from
2. Choose the value of Better, either by typing it in or clicking up/down
3. Choose the value of Much Better, again by typing on clicking the arrows

Note that Better can never have a numeric value larger than much better.

We found that the AHP model successfully differentiated between the cell phone models in a manner consistent with the pairwise comparisons inputted. For instance, the participant shown above simply wants a phone quickly, so price is the major determining factor. This led to the Galaxy S8 winning out, being the

best option on price that we have.

## 10. CUSTOMIZING FOR A DIFFERENT PROBLEM

It is straightforward to customize this work for another consumer choice model. The steps consist of the following:

1. Create the new AHP tree for the model.
2. Define the choices (the alternatives)
3. Get the expert evaluation of the alternatives of the alternatives on the bottom level criteria
4. Design the Google Forms questionnaire and tie its output to a Google sheet
5. Add columns to the Google sheet for the expert evaluations of the alternatives and have a single expert row in the spreadsheet. The column headers should be of the form “AlternativeName wrt Criteria Name”.
6. Make a fork of the code at <https://github.com/wjladams/consumerAHP>
7. In results.js update the line that starts with `<script src=`” <https://spreadsheets.google.com/.....> with the Google sheet URL created above.
8. In Analysis.ipynb update the Google sheet URL.

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# Electric Vehicles Routing Problem With Variable Speed And Time Windows

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**Abstract:** Vehicle routing is a major concern for a distribution channel of any supply chain. It plays a crucial role in attaining a competitive advantage for a company by being cost efficient or responsive. Transportation as a key logistics activity represents a relevant component (generally from 10% to 20%) of the final cost of goods, and one third to two thirds of the cost of logistics. The literature recently shifted towards the use of more energy efficient vehicles. Electric vehicles are characterized by being energy efficient, and do not produce polluting gas emissions such as carbon dioxide. However, the electric vehicles suffer from the limited capacity of the battery and the large charging time. In this paper, the dispatching and routing of battery-operated electric vehicles is considered. The vehicles can move at variable speeds when moving from a customer to another. When the speed is fast, the charge is depleted fast and small number of customers are served in a route. While when the speed is slow, the charge is depleted slowly, and more customers can be accommodated in a route. A genetic algorithm is developed to solve the problem. A piece linear range function based on finite speeds is proposed, as the average speed is used in planning for a given route in real life. A proposed genetic algorithm is proposed and applied on many cases from the literature. The results show that the model is able to optimize the performance and that the model behavior is consistent.

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## 1. INTRODUCTION

Distribution of goods is a main activity in any supply chain. It can help the organization to boost its competitive strategy when it is aligned with the company's strategic objective. Distribution not only has a significant contribution on the product cost, but also results in gas emission and loss of energy. The use of electric vehicles is one of the proposed methods to reduce environmental emission from the distribution network. The large number of real-world applications has widely shown that optimizing the distribution process planning produces substantial savings (Toth and Vigo, 2002). Transportation as a key logistics activity represents a relevant component (generally from 10% to 20%) of the final cost of goods and one third to two thirds the cost of logistics (Swenseth and Godfrey, 2002; Tseng et al. 2005).

Vehicles as main transportation means have recently focused on improving the performance of electric vehicles as they are energy efficient and do not produce gas emissions. However, electric vehicles face several challenges. Storing the electric energy for later use and the drainage of the battery are major research areas with significant improvements to the battery performance introduced. Another concern is the charging time which takes a long period. There is a relation between the limited capacity of the battery which needs a long time to recharge, and the possible range that the vehicle can reach with the change in speed.

This research focuses on studying the routing and dispatching of electric vehicle with time and other resource windows requirements when the range of the vehicle is affected by the travel speed. Due to the trade-off between the speed and the range, when the time window of a customer is not in the immediate future, the EV can move slowly conserving power. In this case, the ability to accommodate more customers

increases. On the other hand, if a vehicle moves faster, it may serve a customer whose time window is very close and cannot be served if the vehicle moves slowly. But, moving fast decreases the vehicle range and hence the ability to accommodate more customers in a route.

The rest of the paper is as follows. In section 2, the relevant literature is reviewed. In section 3, the problem is described along with its assumptions and limitations. A mathematical formulation is also introduced. In section 4, a solution approach is proposed and then tested in section 5. Finally, in section 6, the conclusions and findings are discussed with suggestions of future work.

## 2. LITERATURE REVIEW

The Capacitated constrained VRP (CVRP) is one of the first model introduced to solve the vehicle routing problem (Dantzig and Ramser, 1959). In CVRP, all customers correspond to requested deliveries, and demands are deterministic, known in advance and may not be split. The objective is to minimize the total cost while observing the capacity consumption of the vehicles. When the distance that can be travelled is also a constraint, as in the case of using an electric vehicle, the problem is then called a distance constrained VRP (DCVRP).

CVRP and DCVRP are known to be  $NP$  hard in the strong sense as they are a generalization of the travelling salesman problem (TSP) where there are capacity and distance constraints imposed by the problem.

According to the type of service offered by the distributor, the VRP can be classified into several categories, including Capacitated VRP (CVRP), Distance Constrained VRP (DVRP), VRP with backhauling (VRPB), VRP with Time Windows (VRPTW), VRP with Pickup and Delivery (VRPPD), VRP with Backhaul and Time Windows (VRPBTW), and VRP with Pickup, Delivery and Time Windows (VRPPDTW).

Wang and Shen (2007) consider electric bus scheduling problem that can be defined as a vehicle routing problem with fueling time and range constraints. They consider the objective function of minimizing the number of tours (or vehicles) and minimizing the total deadhead time. They present multiple ant colony algorithms to solve the Traveling Salesman Problem (TSP). They adopt several improvements on the route construction rule, and the pheromone updating rule is adopted.

Several solution approaches are used to solve the VRPTW. Exact solution methods include column generation to the VRPTW is tracked back to Desrosiers et al. (1984). Dumas et al. (1991) extend the problem to pick up-and-delivery with time window. Desrochers (1988) formulates the master problems of a few variations of the VRPTW as set covering problems and the subproblems as non-elementary shortest path problems with resource constraints.

Several variations are applied to the VRPTW such as soft windows as in (Qureshi *et al.*, 2009; and Taş et al., 2014), semi hard resource windows as in (Abdallah and Jang, 2014) stochastic travel times as in (Gutierrez *et al.*, 2018).

When it comes to the electric vehicles, Schneider et. Al. (2014) consider the inclusion of charging stations which consume time. Partial charging is considered in (Keskin and Çatay, 2016). Lin et al. (2016) suggest that the battery consumption is affected by the weight a vehicle carries. An exact solution is developed by Desaulniers et. al. (2016). Gutierrez et al. (2018) consider a log-normal approximation to model the stochastic arrival time and propose a multi-population memetic algorithm to solve the problem. Xu et al. (2019) consider the case of green vehicle routing problem with soft time window. They develop an algorithm based on the non-dominated sorting genetic algorithm (NSGA-II), however, the soft time window is a relaxed model over the model considered in this paper.

## 3. PROBLEM DESCRIPTION

Consider a set  $V$  with  $N$  customers and a depot. Its network is  $G=(V,A)$ , where  $A$  is the set of arcs connecting customers with each other and with the depot, and  $A=\{(i,j): i,j \leq N\}$ . The coordinates of all nodes are known, and the lengths of the arcs are known as the Cartesian distances between their coordinates. Each

customer requires a delivery of a certain quantity  $d_i$  and has an earliest time  $a_i$ , after which the delivery can take place and a latest time  $b_i$ , after which the delivery can not be carried out. The service at each customer takes a given time  $s_i$ . The departure time does not necessarily have to be within the time window, but the service must start within the customer's specified time window. An example of the considered network is shown in figure 1.

There are  $K$  electric vehicles available at the depot, each with capacity  $D$ . The vehicle can start after a given earliest start time and can only return by the latest return time. Without the loss of generality, all the vehicles are assumed to have the same capacity, earliest start times, and latest return times. When a vehicle arrives at a node before the earliest time, the vehicle can wait till the earliest start time to start the service and cannot start the service before this time.

The vehicles start from the depot with a full battery charge. The discharge function  $\varphi^{-1}(i, j, v)$  represents the energy consumed when a vehicle moves from node  $i$  to node  $j$  at speed  $v$ . Each vehicle can use only the attached battery which has a total charge capacity of  $Q$ . The following assumptions are used in the model:

- Each vehicle starts fully charged and return to the depot after completing a route.
- A vehicle performs only one route.
- No intermediate charging occurs.
- The discharging function is known.
- The discharge during the idle time is assumed to be minor and it is not considered in the model.

The following symbols are used in the rest of this paper:

$k$	index of the available $K$ vehicles
$i, j$	index of customers, each customer is represented by a node in the network graph
$x_{ijk}$	binary decision variable for whether arc $i-j$ will be served by vehicle $k$
$c_{ij}$	transportation cost from $i$ to $j$
$D_{ik}$	cumulative demand just before serving customer $i$ by vehicle $k$ . This value is 0 when customer $i$ is not served by vehicle $k$ .
$P_{ik}$	Cumulative power required to visit $i$ using vehicle $k$
$T_{ik}$	cumulative time consumption just before serving customer $i$ by vehicle $k$ . This value is 0 when customer $i$ is not served by vehicle $k$ .
$d_{ij}$	distance between $i$ and $j$
$\Delta^+(i), \Delta(i)$	set of nodes that can be served directly after (before) $i$ in $G(V, A)$
$a_i, b_i$	the lower and upper limit of time window for customer $i$
$S_i$	service time at node $i$ .
$E_i, L_i$	earliest start time and latest return time at the depot
$\varphi(i, j, v)$	energy consumed when a vehicle moves from node $i$ to node $j$ at a speed of $v$ .
$\tau(i, j, v)$	time consumed when a vehicle moves from node $i$ to node $j$ at a speed of $v$ .

$Q_k$  battery  $k$  initial charge

$v$  travel speed

Then the problem can be formulated as follows:

$$\text{Min } \sum_{k \in K} \sum_{(i,j) \in A} c_{ij} x_{ijk} \varphi(i, j, v) \quad (1)$$

Subject to

$$\sum_{k \in K} \sum_{j \in \Delta^+(i)} x_{ijk} = 1 \quad \forall i \in V / \{0, n + 1\} \quad (2)$$

$$\sum_{j \in \Delta^+(0)} x_{0jk} = 1 \quad \forall k \in K \quad (3)$$

$$\sum_{i \in \Delta^-(j)} x_{ijk} - \sum_{n \in \Delta^+(j)} x_{jnk} = 0 \quad \forall k \in K, j \in V / n + 1 \quad (4)$$

$$\sum_{i \in \Delta^-(n+1)} x_{i,n+1,k} = 1 \quad \forall k \in K \quad (5)$$

$$T_{ik} + s_i + \tau(i, j, v) - T_{jk} + M x_{ijk} \leq M \quad \forall (i, j) \in A, \forall k \in K \quad (6)$$

$$(\sum_{j \in V} x_{jik})(a_i) \leq T_{ik} \leq (\sum_{j \in V} x_{jik})(b_i) \quad (i, j) \in A, \forall k \in K \quad (7)$$

$$D_{jk} = \sum_{i \in v'} (x_{ijk} * (D_{ik} + d_j)) \quad \forall i, j \in V, \forall k \in K \quad (8)$$

$$D_{ik} \leq D \quad i \in V, \forall k \in K \quad (9)$$

$$P_{jk} = \sum_{i \in v'} (x_{ijk} * (P_{ik} + \varphi(i, j, v))) \quad \forall i, j \in V, \forall k \in K \quad (10)$$

$$P_{ik} \leq Q_k \quad i \in V, \forall k \in K \quad (11)$$

$$E_i \leq T_{ik} \leq L_i \quad i \in \{0, n + 1\}, \forall k \in K \quad (12)$$

$$P_{0k} = 0, D_{0k} = 0 \quad \forall k \in K \quad (13)$$

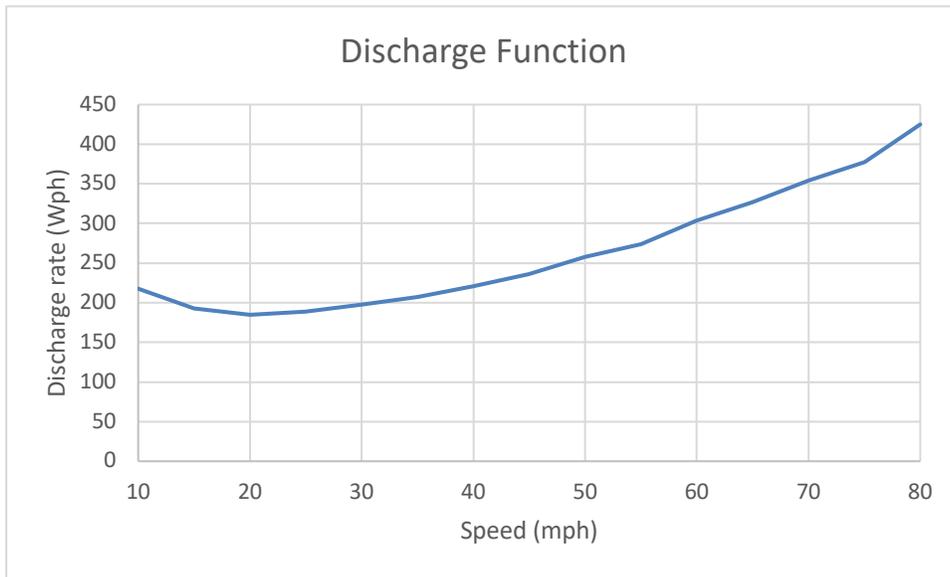
$$x_{ijk} \in \{0, 1\} \quad \forall k \in K, \forall (i, j) \in A \quad (14)$$

The objective function (1) minimizes the total cost. Constraint (2) assigns every customer to just one vehicle. Constraint (3) allows a vehicle to originate from the depot once. Constraint (4) ensures that if a vehicle visits a customer, this vehicle has to leave that customer. Constraint (5) allows a vehicle to reach the depot once. Constraints (6) and (7) ensure that the cumulative time consumption through customer  $i$  when visited by vehicle  $k$  is within the its time window  $[a_i, b_i]$ . Constraints (8) and (9) ensure the total demand of a partial route up to reaching customer  $i$  when visited by vehicle  $k$  does not exceed the vehicle capacity. Constraints (10) and (11) ensure the total power consumption of a partial route up to reaching customer  $i$  when visited by vehicle  $k$  does not exceed the battery capacity. Constraint (12) imposes the boundary conditions at the depot. Constraints (13) and (14) impose the binary conditions.

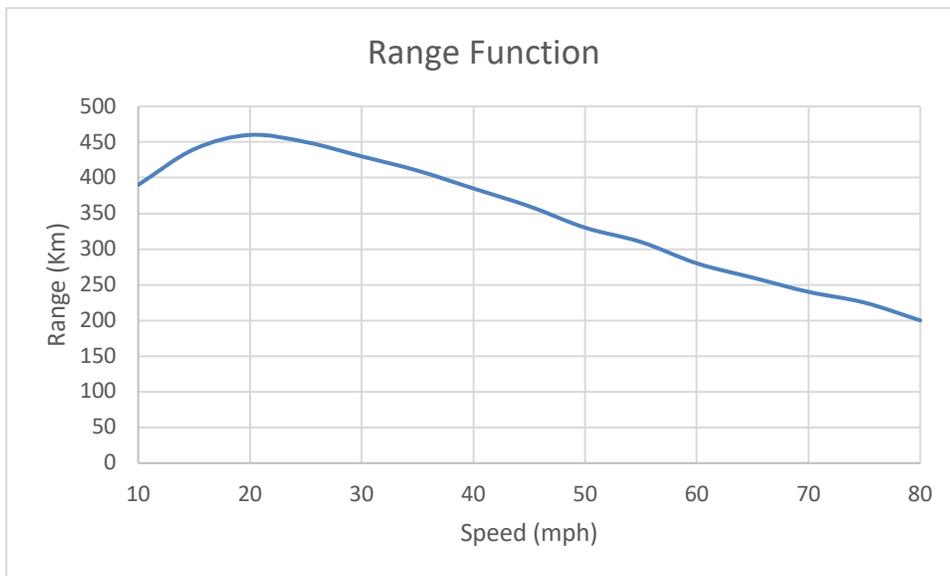
#### 4. SOLUTION APPROACH

A piecewise linear function is used in the proposed model instead of continuous discharging function to represent the power consumption. If a power discharge function is as shown in figure 1, then the range function is as shown in figure 2. As the moving speed between 2 given nodes will vary in the real life, so, a mean speed is used instead. As a result, the range function  $R(v)$  can be approximated by a piece linear function  $R'(v)$  that results from a finite set of speeds  $V = \{v_1, v_2, \dots\}$  as shown in figure 3. The modified discharge function can be represented as  $\varphi^*(i, j, v) = \frac{d_{ij}}{R'(v)} * Q$  where  $d_{ij}$  is the travel distance,  $R'(v)$  is

the piece linear range function, and  $Q$  is the power capacity of the battery.



**Figure 1. Discharge function**



**Figure 2 Range function**

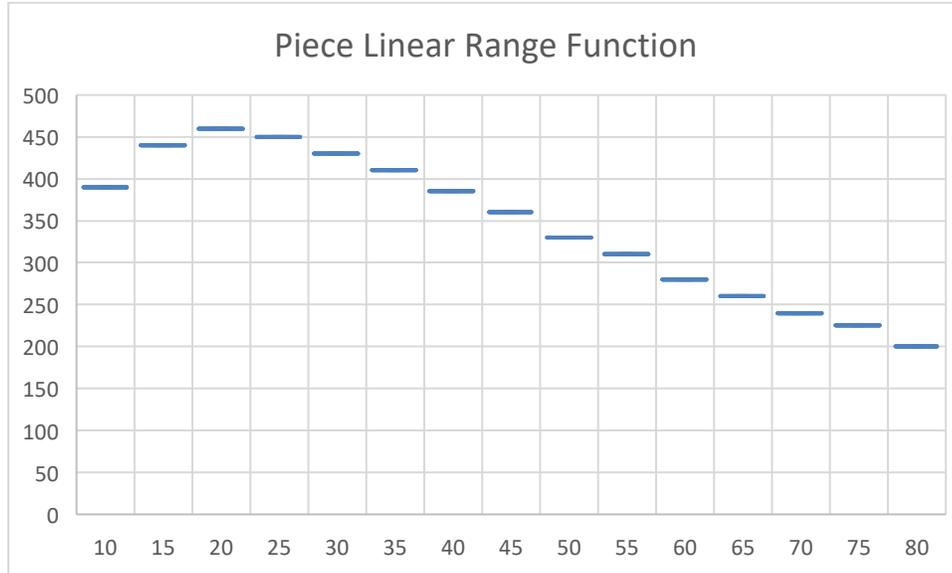


Figure 3 modified function

A genetic algorithm is proposed to solve the formulated problem. The chromosome in the proposed Genetic Algorithm is formed of two parts. The first part consists  $n$  cells that represent the order of visits of the nodes. The second consists of  $n+1$  cells representing the speeds of visiting different nodes. A given chromosome for 4 customers is shown in figure 4.



Figure 4. An example of the used chromosome for 4 customers.

The first part of the chromosome is used to interpret the visit order. Each vehicle is considered to follow the sequence in the chromosome until there is a customer that cannot be served in the current route under investigation due to various resources constraints. If the vehicle can feasibly return to the depot (i.e., satisfying the depot constraints), the route of the current vehicle is considered finished, and a new vehicle is considered. Otherwise, the last customer is dropped. This is repeated until the vehicle can feasibly return to the depot, and a new route using a new vehicle is started by the last dropped customer.

The second part of the chromosome is used in conjunction with the first part as the moving speed. When the first vehicle moves from the depot to the node of the first cell of the first part, it moves at the speed in the corresponding cell in the second part. The vehicle then moves to the node in the second cell in the first part using the speed in the second cell in the second part. The vehicle keeps moving at the corresponding speed until deciding from the first part that the vehicle needs to return to depot. The return speed is then determined as the slowest feasible speed to reach the depot. This is achieved by selecting the slowest speed to return, and compute the feasibility of the resource requirement. If not feasible, the next speed is selected and tested. This is repeated until reaching a feasible return speed. If there is no feasible speed to satisfy the resource requirements, the current node is dropped from the current vehicle route and the possibility to move from the previous node in the chromosome to the depot is examined. A new vehicle is considered to be moving from the depot to the first unassigned customer in the first part of the chromosome using the first unassigned speed in the second part of the chromosome. The algorithm is then repeated until all the nodes are visited.

It should be noted that that procedures require the first part of the chromosome as a permutation of the  $n$  nodes (customers). While the second part needs to be of  $n+1$  cell length.

When computing the fit of a chromosome, the fitting function computes the time, cumulative demand,

cumulative power consumption, and the number of vehicles required to reach the next node from the current node. If the chromosome can serve all the customers feasibly, then the fit function returns the cost of the route (i.e., the sum of the cost of the power consumed, the cost of labor time and the fixed cost).

The initial population is formed by random permutation of the  $n$  customers available for the first part of the chromosomes, and then, random generation of one of the available speeds for a vector of size  $n+1$  for the second part.

Several types of crossovers are used in the proposed algorithm. Two parents are selected and the first part of the chromosomes (i.e., the routing part) are exchanged keeping the speed part as shown in figure 5.

Another type of crossover is used by creating a binary vector  $r$  with a size that is equal to the chromosome's size. The first part of the vector is initialized with zero values. Then two numbers are generated randomly. These are used as start and end points of a portion of the generated vector that are replaced by ones rather than zeros. The second part of the generated vector  $r$  is formed of random binary values.

The generated child is formed by taking two parents and follow the sequence of the generated vector in different ways for the first and second parts. For the first part, if the current cell in vector  $r$  is 0, we take the content of the current cell from the first parent (e.g. 3), delete it from the first parent, and delete the cell with the same content of that cell (e.g. 3) from the second parent. If the current cell contains 1, we do the same but we take it from the second parent and delete it from the first parent. This is illustrated in figure 6. For the second part of the chromosomes, if the corresponding cell in vector  $r$  is zero, then the child inherits the current cell from the first parent; and, inherits it from the second parent if it is one.

Parent 1	3	2	4	1	1	2	2	4	3
Parent 2	2	4	1	3	3	1	1	2	4
Child 1	2	4	1	3	1	2	2	4	3
Child 2	3	2	4	1	3	1	1	2	4

Figure 5. Crossover of the first part of the chromosomes.

Parent 1	3	2	4	1	1	2	2	4	3
Parent 2	1	3	4	2	3	1	1	2	4
r	0	1	1	0	0	0	1	0	1
Child	3	1	4	2	1	2	1	4	4

Figure 6. Crossover for visiting order and speed

For the mutation, two ways of mutation are used. For the first part of the chromosome, a random value is generated corresponding to a cell. Then the content this cell is swapped with the cell whose order is equivalent to the content of the generated cell number. In figure 7, if the generated number is one, then the 1<sup>st</sup> cell is swapped with the 3<sup>rd</sup> cell where 3 is the content of the first cell.

The second mutation is for the second part of the chromosome (i.e., the speed part of the chromosome). A random number is generated, then the content of the cell with the generated order is randomly generated from the available mean speeds in the stepwise linear function proposed above. An example is illustrated in figure 8 where the fifth cell speed is changed from 3 to 2.

Parent	3	2	4	1
Mutated chromosome	4	2	3	1

Figure 7. Mutation visiting order when the first cell is chosen. Content of the first cell is replaced with the cell order as in the first cell (i.e., content of cell 3 which is 4).

Parent	1	3	4	2	3	1	1	2	4
Child	1	3	4	2	2	1	1	2	4

Figure 8. Mutation of the speed for the first cell in the second part of the chromosome.

### 5. NUMERICAL RESULTS

The numerical experiments were developed via MatLab 2016 on an intel i5-3470 at 3.2 GHz and 4 GB ram. The test data used is Solomon’s data set (Solomon, 1987). The data sets used are for 100 customers for random (r), clustered (c), and mixed (rc) customers. We solve for 25, 50 and 100 customers. When solving for 25 (50) customers, we consider the first 25 (50) customers of the 100 customers given in any data set. There are 3 speed steps used in the numerical testing 15, 30, and 45 mph.

The initial population is formed of 50 parents. The routing parts are formed of a random permutation of the  $n$  customers chosen. The second parts of the chromosomes are formed as vectors of size  $n+1$  containing random values representing one of the speeds available.

The numerical testing is carried out to answer two questions. The first question is whether the proposed model improves the performance over using a fixed speed or not, and the second question is whether the proposed model is reliable when a test is replicated.

To answer the first question, the developed model using the same code is applied to all the test cases and replicated 3 times for the case of a fixed speed 15 mph, then, another time for the case when variable speeds are allowed. The best answer for each case is recorded and compared as shown in tables 1-3 for  $r$  data sets,  $c$  data sets, and  $rc$  data sets; respectively. The proposed model is able to find a better solution in all the cases. This shows the practical importance of the model. The model is able to overcome the tight time and distance constraints by moving the vehicles at a faster speed. This takes place despite the rapid depletion of the battery and the higher cost of the moving faster.

Table 1. Comparison of the best solution without speed variation vs the best solution when speed variation is allowed for the r data sets.

	R								
	25			50			100		
	One Speed	Variable speed	Cost reduction	One Speed	Variable speed	Cost reduction	One Speed	Variable speed	Cost reduction
101	3323.09	2773.81	16.5%	6999.34	5869.08	16.1%	13305.1	11184.6	15.9%
102	2645	2124.27	19.7%	5624.46	4548.14	19.1%	10674.9	8664.67	18.8%
103	1898.22	1476.2	22.2%	3992.7	3164.72	20.7%	7382.78	5858.46	20.6%
104	1510.63	1134.56	24.9%	2275.1	1696.06	25.5%	4394.96	3519.22	19.9%
105	1331.16	955.208	28.2%	2340.56	2005.75	14.3%	4426.34	3720.17	16.0%
106	1212.17	876.566	27.7%	2099.79	1702.35	18.9%	3748.71	3284.06	12.4%
107	1154.43	785.355	32.0%	1902.61	1561.64	17.9%	3502.96	2858.83	18.4%
108	1061.97	746.326	29.7%	1862.65	1344.47	27.8%	3131.22	2936.81	6.2%
109	1200.9	788.559	34.3%	2053.27	1546.11	24.7%	3629.42	3090.24	14.9%
110	1027.99	734.463	28.6%	1993.03	1437.4	27.9%	3159.59	2612.43	17.3%
111	1100.46	810.965	26.3%	2030.22	1425.57	29.8%	3557.25	2668.19	25.0%
112	993.064	703.946	29.1%	1807.15	1361.09	24.7%	3261.4	2497.53	23.4%

To answer the second question about the reliability of the model when it is run several time using the same parameters, the proposed model is run three times, then the best value is compared to the mean value of each data set as shown in table 4-6. The value chosen for the comparison is the decrease in the solution relative to the mean solution (i.e., (mean-best)/mean)). From the table, it could be concluded that the proposed model is neither sensitive to the increase of the number of customers nor to the distribution of the customers (i.e., random, clustered, or mixed). The decrease in the solution relative to the mean does not exceed 6.2%.

**Table 2. Comparison of the best solution without speed variation vs the best solution when speed variation is allowed for the c data sets.**

	C								
	25			50			100		
	One Speed	Variable speed	Cost reduction	One Speed	Variable speed	Cost reduction	One Speed	Variable speed	Cost reduction
<b>101</b>	3019.19	2513.85	16.7%	6430.57	5391.43	16.2%	15389.2	12935.9	15.9%
<b>102</b>	2323.91	1868.29	19.6%	4859.51	3973.54	18.2%	11920.9	9790.66	17.9%
<b>103</b>	1433.78	1132.8	21.0%	3307.85	2628.36	20.5%	8016.6	6463.5	19.4%
<b>104</b>	1011.17	788.456	22.0%	1649.67	1268.53	23.1%	4755.96	3782.3	20.5%
<b>105</b>	691.887	509.76	26.3%	1543.83	1274.69	17.4%	4458.91	4284.85	3.9%
<b>106</b>	2494.13	2010.08	19.4%	4068.75	3296.08	19.0%	6091.58	5534.44	9.1%
<b>107</b>	511.503	453.931	11.3%	1267.66	1034.31	18.4%	3964.46	3468.8	12.5%
<b>108</b>	511.503	428.41	16.2%	1114.55	1013.99	9.0%	3581.06	3524.98	1.6%
<b>109</b>	511.503	452.526	11.5%	1130.35	908.899	19.6%	3498.87	3100.59	11.4%

**Table 3. Comparison of the best solution without speed variation vs the best solution when speed variation is allowed for the rc data sets.**

	RC								
	25			50			100		
	One Speed	Variable speed	Cost reduction	One Speed	Variable speed	Cost reduction	One Speed	Variable speed	Cost reduction
<b>101</b>	1108.04	862.146	22.2%	2544.6	1992.74	21.7%	4803.13	4469.11	7.0%
<b>102</b>	924.398	809.706	12.4%	2073.44	1849.63	10.8%	4774.27	3738.58	21.7%
<b>103</b>	885.447	665.754	24.8%	2055.13	1548.22	24.7%	4326.22	3629.58	16.1%
<b>104</b>	800.625	605.503	24.4%	1815	1615.96	11.0%	4242.89	3386.71	20.2%
<b>105</b>	1796.69	1436.51	20.0%	3313.37	2708.53	18.3%	6579.76	5414.97	17.7%
<b>106</b>	911.253	691.693	24.1%	2144.48	1765.07	17.7%	4154.52	3647.13	12.2%
<b>107</b>	791.549	600.763	24.1%	1972.41	1608.68	18.4%	4239.66	3568.85	15.8%
<b>108</b>	790.699	600.148	24.1%	2008.06	1521.07	24.3%	4076.38	3290.31	19.3%

**Table 4. Comparison of the best solution and the mean solution among replications for the r data sets.**

	r								
	25			50			100		
	Best	Mean	□	Best	Mean	□	Best	Mean	□
<b>101</b>	2773.8	2773.8	0.0%	5869.1	5869.1	0.0%	11184.6	11184.6	0.0%
<b>102</b>	2124.3	2124.3	0.0%	4548.1	4552.3	0.1%	8664.7	8680.2	0.2%
<b>103</b>	1476.2	1489.7	0.9%	3164.7	3179.2	0.5%	5858.5	5932.5	1.2%
<b>104</b>	1134.6	1168.4	2.9%	1696.1	1715.0	1.1%	3519.2	3563.7	1.2%
<b>105</b>	955.2	979.1	2.4%	2005.8	2040.2	1.7%	3720.2	3780.8	1.6%
<b>106</b>	876.6	905.9	3.2%	1702.4	1770.8	3.9%	3284.1	3375.8	2.7%
<b>107</b>	785.4	809.3	3.0%	1561.6	1618.1	3.5%	2858.8	3049.2	6.2%
<b>108</b>	746.3	747.1	0.1%	1344.5	1378.7	2.5%	2936.8	2951.2	0.5%
<b>109</b>	788.6	821.4	4.0%	1546.1	1556.5	0.7%	3090.2	3172.1	2.6%
<b>110</b>	734.5	758.6	3.2%	1437.4	1516.3	5.2%	2612.4	2702.0	3.3%
<b>111</b>	811.0	815.5	0.6%	1425.6	1469.7	3.0%	2668.2	2813.2	5.2%
<b>112</b>	703.9	718.2	2.0%	1361.1	1377.2	1.2%	2497.5	2527.3	1.2%

**Table 5. Comparison of the best solution and the mean solution among replications for the c data sets.**

	c								
	25			50			100		
	Best	Mean	□	Best	Mean	□	Best	Mean	□
<b>101</b>	2513.9	2513.9	0.0%	5391.4	5391.4	0.0%	12935.9	12935.9	0.0%
<b>102</b>	1868.3	1869.1	0.0%	3973.5	3981.0	0.2%	9790.7	9798.1	0.1%
<b>103</b>	1132.8	1136.2	0.3%	2628.4	2645.9	0.7%	6463.5	6521.9	0.9%
<b>104</b>	788.5	799.4	1.4%	1268.5	1309.3	3.1%	3782.3	3927.8	3.7%
<b>105</b>	509.8	511.8	0.4%	1274.7	1290.7	1.2%	4284.9	4365.6	1.8%
<b>106</b>	2010.1	2011.7	0.1%	3296.1	3322.2	0.8%	5534.4	5586.1	0.9%
<b>107</b>	453.9	464.1	2.2%	1034.3	1093.0	5.4%	3468.8	3661.7	5.3%
<b>108</b>	428.4	442.2	3.1%	1014.0	1045.5	3.0%	3525.0	3707.2	4.9%
<b>109</b>	452.5	456.8	0.9%	908.9	947.2	4.0%	3100.6	3276.5	5.4%

## 6. CONCLUSIONS AND FUTURE WORK

Recently, there has been an increasing interest in reducing gas emissions from different transportation means. Hybrid and battery-operated vehicles serve this purpose as they do not consume power while idle, and, the efficiency of the motor is relatively high. However, storing electricity, the capacity of the batteries, and the charging time are major challenges. This research focuses on routing a fleet of electric battery-operated vehicles that can move at different speeds consuming different powers. The batteries are assumed to be fully charged at the beginning and the different customer requirements are satisfied.

The paper introduces a proposed genetics algorithm that is based on the idea that, for practical reasons, the cost of operating a vehicle on a route is, most of the time, evaluated using the average vehicle speed.

Moreover, in actual life, there may be a deviation from a fixed speed, so again the average speed could be used. So, the model proposed in this paper utilizes a piece-linear range function resulting from the average travel speed of a vehicle. It should be noted that increasing the number of speed steps in the proposed model makes the model close to the continuous case.

The proposed model was tested using Solomon’s datasets. The model was proved to be effective in improving the solution over the case when a single speed is used and reliable in finding consistent solutions. The model shows that increasing the speed limits the range for the car and hence limits the number of customers that could be served along a route. On the other side, moving slowly extends the range and the ability to accommodate more customers; however, the slow serving time limits the number of customers. The proposed helps improving the performance under these trade-offs. Variable speeds can overcome the obstacles of tight windows or distance constrains at the expense of the battery capacity. The model is capable of routing the vehicles to satisfy the customer needs (demand, time...etc.) in addition to determining the average speed a vehicle should run at when moving between two successive customers.

This model can be extended in different ways for future works. The model can be extended to include intermediate charging stations, allow multi route for the vehicle, and include multiple routes.

**Table 6. Comparison of the best solution and the mean solution among replications for the rc data sets.**

	rc								
	25			50			100		
	Best	Mean	□	Best	Mean	□	Best	Mean	□
101	862.1	903.0	4.5%	1992.7	2066.2	3.6%	4469.1	4646.6	3.8%
102	809.7	831.8	2.7%	1849.6	1930.8	4.2%	3738.6	3850.4	2.9%
103	665.8	672.1	0.9%	1548.2	1612.9	4.0%	3629.6	3651.6	0.6%
104	605.5	612.0	1.1%	1616.0	1683.6	4.0%	3386.7	3574.9	5.3%
105	1436.5	1471.8	2.4%	2708.5	2830.2	4.3%	5415.0	5490.4	1.4%
106	691.7	755.2	8.4%	1765.1	1833.7	3.7%	3647.1	3789.1	3.7%
107	600.8	616.1	2.5%	1608.7	1671.7	3.8%	3568.9	3679.1	3.0%
108	600.1	603.0	0.5%	1521.1	1573.5	3.3%	3290.3	3422.2	3.9%

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# **Integrating BIM in Construction Takeoff and Estimating: A Case Study of an Advanced Cost Estimating Course for Construction Management**

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**Abstract:** As Building Information Modeling (BIM) is becoming the standard practice for design, engineering, and fabrication in the construction industry, Construction Management (CM) programs have started to introduce BIM for cost estimating in their curriculum. Many CM programs consider model-based quantity takeoff merely as an alternative approach to the traditional plan-based quantity takeoff. The disconnection between automated quantity takeoff and cost estimating, however, still exists. In addition, without fully understanding the role of BIM in preconstruction, students will only use BIM models as 3D representation of the plans without realizing the benefits that the BIM process brings to the project lifecycle. This paper presents a newly developed Advanced Cost Estimating course for CM programs that focuses on integrating BIM in both the takeoff and estimating process. The course is structured based on the UniFormat divisional system and uses RSMeans building assemblies for bid pricing. The course streamlines the connection between model-based quantity takeoff and cost estimating with the help of the latest construction software programs. By applying a combination of three different computer programs, quantity data from a BIM model can be seamlessly transferred to a construction cost database for bid pricing and reporting. Student survey at the end of semester suggested that using BIM models for construction takeoff and estimating with building assemblies can greatly improve student understanding of knowledge and consequently strengthen the learning outcomes. This paper provides an empirical case study with valuable insights on how to integrate BIM in a cost estimating course in a CM program.

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## **1. INTRODUCTION**

As the construction industry has adopted Building Information Modeling (BIM) as the standard practice for design, engineering, and fabrication, Construction Management (CM) programs in the U.S. have been actively introducing BIM in their curriculum for various construction-related topics, including cost estimating. Many, however, consider model-based quantity takeoff merely as an alternative approach to the traditional plan-based quantity takeoff, and there is still a disconnection between model-based quantity takeoff and automated cost estimating. With the advancement of construction software programs in recent years, this connection has been established and new approaches have emerged for cost estimating with BIM.

Based on the latest technologies, this paper presents a newly developed Advanced Cost Estimating course for CM programs that focuses on integrating BIM in both the takeoff and estimating process. The objectives of developing the Advanced Cost Estimating course are to:

- 1) Introduce BIM for cost estimating in a CM program;
- 2) Connect model-based quantity takeoff to automated cost estimating;
- 3) Practice assembly takeoff and estimating with a computer-based cost database; and
- 4) Prepare CM students for a comprehensive cost estimate in the capstone course.

By applying a combination of three different computer programs, quantity data from a BIM model can be seamlessly transferred to a construction cost database for bid pricing and reporting. This paper provides an empirical case study with valuable insights on how to integrate BIM in a cost estimating course in a CM program.

## **2. BACKGROUND**

### **2.1. Bim In Cm Education**

According to a survey by Pavelko and Chasey (2010), out of 59 ACCE-accredited Associated Schools of Construction member programs, 70% already had included BIM contents in 2010, of which about a third had taught BIM for cost estimating. In a similar survey by Joannides et al. (2012), out of 35 ACCE-accredited construction programs, 83% had covered BIM contents in 2012, of which one fifth had BIM-related cost estimating topics.

Huang (2018) summarized the different approaches the various CM programs had adopted to incorporate BIM in their curriculum, including standalone courses, cross-discipline courses, capstone/project courses, and integration into existing courses.

Introducing BIM in standalone courses is an effective approach to quickly cover BIM components. Many CM programs introduce BIM in a standalone course to replace an existing lower level CAD course, such as Digital Graphical Representation, Graphical Communication, and Construction Information Technology (Taylor et al., 2008; Barison and Santos, 2010). These courses often focus on the specific skills of 3D modeling in Autodesk Revit or Trimble SketchUp (Sacks and Barak, 2010; Sacks and Pikas, 2013).

Some CM programs introduce BIM by allowing students to take cross-discipline courses from other programs such as civil engineering workshops and architecture studios (Lee and Hollar, 2013). While this approach is efficient at some extent and takes the maximal use of existing resources, these cross-discipline courses often focus towards design and away from CM topics.

Implementing BIM in a capstone project allows students to learn the BIM process in various CM subjects throughout the project cycle (Ghosh et al., 2015). However, teaching BIM within a one- or even two-semester capstone project limits the use of BIM in each CM discipline to only a couple of weeks due to time constraint. As a result, students get only a basic understanding of the BIM process and their BIM skills fall short of the expectation to become fluent.

Integrating BIM into existing courses is considered the most practical way to offer BIM (Lee and Dossick, 2012). This strategy typically divides BIM contents into smaller and manageable topics, and thus can provide CM students with a rich and rigorous learning environment and consequently better quality of education (Sacks and Pikas, 2013).

### **2.2. BIM In Quantity Takeoff**

BIM models have made the quantity takeoff process significantly easier over 2D drawings because the 3D objects have contained dimension and material information. Depending on its Level of Development, a BIM model can be used for quantity takeoff at various stages of a project for different accuracy levels. Many BIM programs have the capability of performing model-based quantity takeoff. Eberhardt et al. (2018) compared students' uses of Autodesk Revit and Autodesk Navisworks for quantity takeoff in an estimating course. Elliot et al. (2019) examined student perceptions of using Autodesk Revit for quantity takeoff in an estimating course. Both studies, however, focused only on model-based quantity takeoff and did not connect with cost estimating despite describing the tasks as model-based estimating.

In addition to Revit and Navisworks, Table 1 lists other available BIM software programs for quantity takeoff along with the required module or version. These programs can either open a local model in AutoCAD, Revit, Navisworks, or Tekla file type, or connect to BIM 360 and access the model from the cloud service. The programs also work differently when performing model-based quantity takeoff. Some programs simply take off everything within the model and present a master spreadsheet, such as Assemble

and Revit, while others allow individual object takeoff, such as Navisworks, Vico Office, and Innovaya Visual Quantity Takeoff.

**Table 1. List of BIM software programs for quantity takeoff**

Developer	Takeoff Program	Module/ Version	Model Source
Autodesk	Assemble		BIM 360/ Navisworks
Beck Technology	DESTINI Estimator		BIM 360/ Navisworks
Autodesk	Navisworks Manage	Quantification	AutoCAD/ Navisworks / Revit
Autodesk	Revit	Schedule	Revit
Sigma	Sigma Estimates	Enterprise	BIM 360/ Revit
Trimble	Vico Office	Cost Planner	Revit/ Tekla
Innovaya	Visual Quantity Takeoff		AutoCAD/ Revit/ Tekla

### 2.3. BIM In Cost Estimating

Connecting model-based quantity takeoff to a construction cost database is required to perform cost estimating and generate cost reports, which used to be a challenge for model-based estimating due to the lack of available software programs. With the technology advancement in recent years, a handful estimating programs are able to connect a takeoff source to a cost database, which bridges the gap and enables the workflow of model-based takeoff and estimating.

Table 2 presents a list of available software programs that are able to perform model-based cost estimating. Some programs contain the quantity takeoff module within itself as a full package, such as DESTINI Estimator, Sigma Estimates, and Vico Office, while others need to connect to a quantity takeoff program as the data source. eTakeoff Bridge can connect to either Assemble or Navisworks while Innovaya Visual Estimating needs to access quantity data from its own Visual Quantity Takeoff. Once the quantity data is ready, the estimating program will access a cost database to apply a unit price to the quantity of each cost item in the takeoff. Some programs can access the RSMeans cost database as a standard construction cost database. eTakeoff Bridge and Innovaya Visual Estimating access the RSMeans cost database by further connecting with Sage Estimating while the RSMeans cost database is integrated with Sage Estimating. Sigma Estimates allows the RSMeans cost database to be directly imported to the program for cost estimating. In other programs, a customized cost database needs to be created before estimating, such as DESTINI Estimator and Vico Office.

**Table 2. List of BIM software programs for cost estimating**

Developer	Estimating Program	Takeoff Source	Cost Database
eTakeoff	Bridge	Assemble/ Navisworks	Sage + RSMeans
Beck Technology	DESTINI Estimator	Native	Custom
Sigma	Sigma Estimates	Native	RSMeans/ Custom
Trimble	Vico Office	Native	Custom
Innovaya	Visual Estimating	Visual Quantity Takeoff	Sage + RSMeans

## 3. CASE STUDY: ADVANCED COST ESTIMATING

### 3.1. Course Overview

The Advanced Cost Estimating course aims to focus on additional quantity takeoff and cost estimating skills beyond the basic Cost Estimating course that students already took as a prerequisite. These skills include using BIM models for quantity takeoff, streamlining model-based takeoff and cost estimating with

Sage Estimating, applying RSMMeans Assembly cost database, and creating a summary-level cost estimate with Sage Estimating. Eventually, the Advanced Cost Estimating course prepares CM students for the capstone course where they will be required to create a bid package including a comprehensive cost estimate.

Based on the available BIM software programs for quantity takeoff and cost estimating and how they interact with each other, the available workflow of integrated model-based takeoff and estimating methods is summarized in Table 3. According to the course goals, Sage Estimating and the RSMMeans cost database are required for CM students. Due to the popularity of Navisworks in the CM field and eTakeoff Bridge being bundled with Sage Estimating, the workflow of Navisworks model + Navisworks Manage + eTakeoff Bridge + Sage Estimating with RSMMeans database was selected as the software programs for the Advanced Cost Estimating course.

**Table 3. Available workflow of integrated model-based takeoff and estimating methods**

<b>Model Source</b>	<b>Takeoff Program</b>	<b>Estimating Program</b>	<b>Cost Database</b>
BIM 360/ Navisworks	Assemble	eTakeoff Bridge	Sage + RSMMeans
AutoCAD/ Navisworks / Revit	Navisworks Manage	eTakeoff Bridge	Sage + RSMMeans
BIM 360/ Revit	Sigma Estimates	Native	RSMMeans
AutoCAD/ Revit/ Tekla	Visual Quantity Takeoff	Visual Estimating	Sage + RSMMeans

### 3.2. Course Objectives

Five course objectives were developed to match the course goals and in the meanwhile align with the six levels of cognitive learning process in Bloom’s Taxonomy, which are “remember, understand, apply, analyze, evaluate, and create” from lower- to higher-order thinking skills (Anderson et al., 2001). As shown in Table 4, Objective 1 “Describe different construction cost estimating types and methods” belongs to lower-level cognitive learning process “remember” and “understand”, and Objective 2 “Compare the MasterFormat and UniFormat divisional systems” and Objective 3 “Explain the BIM process and its relevant concepts” align with lower- to mid-level cognitive learning process “understand” and “apply.” Objective 4 “Demonstrate model-based quantity takeoff with a BIM program” covers mid-level cognitive learning process “apply” and “analyze” and Objective 5 “Create a comprehensive construction cost estimate with a computer-based RSMMeans cost database” aims higher-level cognitive learning process “evaluate” and “create.”

**Table 4. Course objectives associated with Bloom’s taxonomy**

<b>Course Objectives</b>	<b>Bloom’s Taxonomy</b>
1. Describe different construction cost estimating types and methods	Remember and understand
2. Compare the MasterFormat and UniFormat divisional systems	Understand and apply
3. Explain the BIM process and its relevant concepts	Understand and apply
4. Demonstrate model-based quantity takeoff with a BIM program	Apply and analyze
5. Create a comprehensive construction cost estimate with a computer-based RSMMeans cost database	Evaluate and create

### 3.3. Course Layout

Over twenty course topics were developed to meet the needs of the five course objectives during a fourteen-week schedule not including time for exams, as detailed in Table 5. The first two weeks focus on introducing different types of conceptual estimating, refresh unit price estimating, which was covered in

the prerequisite Cost Estimating course, and compare it with assembly estimating, which is the primary estimating method in this course. These topics fulfill the needs of Objectives 1 and 2.

In the next two weeks, the course switches to BIM-related topics, including the BIM process, the evolvment and management of federated model, and the Level of Development (LOD). Students start to learn the basic navigation of Navisworks, including display options, the selection tree, creating sets, and search features, and get ready for the upcoming model-based quantity takeoff. These topics fulfill the requirements of Objective 3.

The majority of course topics occur between week 5 and week 12 when individual assemblies are introduced, followed by a computer lab session for each topic, which covers from concrete foundation, masonry, steel framing, to insulation and interior finish. Using the UniFormat divisional system, students are instructed to take off selected assemblies within a federated model using Navisworks, locate the same assembly item and complete the required quantity inputs in eTakeoff Bridge, and send the assembly estimate to Sage Estimating. The federated model contains most of the assembly types and is used throughout all the assembly topics. These topics satisfy the requirements of Objective 4.

During the last two weeks, students learn to combine all separate estimates created in previous weeks using Sage Estimating and add additional items to the total cost, such as general conditions, profit, and contingency. Students then create different types of cost reports, including detail- or summary-level cost estimates by UniFormat divisions or assemblies. The final task as the course project is to develop a similar cost estimate report with all the knowledge and skills learned for a different federated model and submit a total price for bidding. The course project is designed as a group project for two to three members per group and is allocated with class time for students to complete.

**Table 5. Course topics associated with objectives and schedule**

<b>Course Objectives</b>	<b>Course Topics</b>	<b>Course Schedule</b>
1. Describe different construction cost estimating types and methods	Conceptual Estimating	Week 1
	Unit Price Estimating	Week 2
2. Compare the MasterFormat and UniFormat divisional systems	Assembly Estimating	Week 2
	Unit Price Estimating	
3. Explain the BIM process and its relevant concepts	Assembly Estimating	Week 3
	Federated Model	
4. Demonstrate model-based quantity takeoff with a BIM program	Level of Development	Week 4
	Introduction to Navisworks	
	Strip Footings	Week 5
	Spread Footings	Week 6
	Slab on Grade	
	Concrete Columns & Beams	Week 7
	Concrete Walls	
	Slab over Metal Decking	Week 8
	CMU & Brick	
	Steel Columns	Week 9
	Steel Beams	Week 10
	Steel Joists, Girders & Trusses	
Cold Formed Framing	Week 11	
Dampproofing & Waterproofing		
5. Create a comprehensive construction cost estimate with a computer-based RSMMeans cost database	Building Insulation	Week 12
	Metal Studs & Drywall	
	Wood Framing & Drywall	Week 13
	Estimate Summary	
	Project Work Day 1	Week 14
Project Work Day 2		

### 3.4. Course Assessment

The course uses a weighted grading system with six categories including participation (10%), seven assignments (25%), fifteen labs (25%), midterm exam (10%), final exam (15%), and project (15%). Participation includes five times of random sign-in throughout the semester. Assignments include short answer questions, manual conceptual estimating questions, and model-based takeoff and estimating questions. Both exams have a close-book multiple-choice and terminology section and an open-book model-based takeoff and estimating section. The project, as described earlier, is a small-group project.

Each course objective is assessed against the assessment criteria presented in Table 6 by at least two assessment methods. Objectives 1 and 2 are assessed by two assignments and multiple-choice questions in the exams to evaluate students' ability to select a correct method for any given project information and to locate cost information in different divisional systems, respectively. Objectives 3 and 4 are assessed by five assignments, fifteen lab reports, terminology questions, and model-based takeoff and estimating questions in the exams to evaluate students' ability to identify LOD levels and navigate in a federated model, and perform quantity takeoff with Navisworks and develop cost estimates with eTakeoff Bridge, respectively. Objective 5 is assessed by the course project to evaluate students' ability to create a Sage cost estimate report with RSMMeans database.

**Table 6. Assessment methods and criteria for each course objective and course topics**

Course Objectives	Course Topics	Assessment Methods	Assessment Criteria
1. Describe different cost estimating types and methods	Conceptual Estimating Unit Price Estimating Assembly Estimating	Assignments, exams	Ability to select a correct method for any given project information
2. Compare MasterFormat and UniFormat divisional systems	Unit Price Estimating Assembly Estimating	Assignments, exams	Ability to locate cost information in different divisional systems
3. Explain the BIM process and its relevant concepts	Federated Model Level of Development Intro to Navisworks	Assignments, labs, exams	Ability to identify LOD levels and navigate in a federated model
4. Demonstrate model-based takeoff with BIM program	17 different assemblies	Assignments, labs, exams	Ability to perform quantity takeoff with Navisworks
5. Create a cost estimate with a computer-based RSMMeans cost database	Estimate Summary Project Work Days	Project	Ability to create a Sage cost estimate report with RSMMeans database

### 3.5. Course Evaluation

Since this course has only been offered for the first time, inadequate information on student performance and feedback were collected to evaluate the course. Nevertheless, student survey at the end of semester suggested that using BIM models for construction takeoff and estimating with building assemblies can greatly improve student understanding of knowledge and consequently strengthen the learning outcomes. Future research will continue on course evaluation via the following methods:

- 1) Monitor student performance in each course objective. The student performance goal of the CM program is that 80% of student achieve 70% or above grade. The course will adopt this goal for each course objective and monitor the percentages of students meeting the goal.
- 2) Conduct student surveys at the end of the semester. The survey includes a unified student rating of instruction (SROI) used across the university and a questionnaire specifically designed for this course. The SROI will be used to track the performance of course materials and instruction. The questionnaire will record students' ratings and comments on each topic

of the course, including the difficulty of lecture and lab materials, the readiness of lab programs and equipment, the shortcomings and potential improvements, etc. The feedback of questionnaires will be used to improve future course offerings.

- 3) Compare and analyze the evaluation results of both student performance and student surveys in each course offering. The comparison and analyses will be used to track the course performance over time and improve overall course quality.

#### 4. CONCLUSIONS

As Building Information Modeling (BIM) is becoming the standard practice for design, engineering, and fabrication in the construction industry, model-based quantity takeoff and cost estimating has been a new trend over the traditional plan-based approach. There is, however, a disconnection between automated quantity takeoff and cost estimating in many CM programs in the U.S. This paper presents a newly developed Advanced Cost Estimating course for CM programs that focuses on integrating BIM in both the takeoff and estimating process and provides an empirical case study with valuable insights on how to integrate BIM in a cost estimating course in a CM program.

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## Developing a Decision Support Tool for Quantification and Reduction of Construction Material Waste

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**Abstract:** The construction industry has a major impact on the environment, both in terms of resource consumption and waste production. Given the high rate of raw materials wastage and ineffective waste management frequently conducted on construction sites, waste minimization strategies have become an important area of concern in the construction industry. However, the knowledge of origins and distribution of construction waste is very limited. This gap in knowledge limits the effectiveness of decisions made to reduce construction waste at the design and planning phase. The University of Alabama Construction Administration department (UACA) provides management and support for construction projects on campus. In this paper, the application of decision support system (DSS) technology is investigated to support UACA interest in construction material waste management. DSS are software systems that utilize sophisticated algorithmic approaches to solve problems. The utilization of technologies, such as Building Information Modeling (BIM), in construction has allowed for more efficient, better designed structures that limit the waste of resources, optimize energy use, and promote passive design strategies. The objectives of this research are to quantify construction waste, determine its causes, and lead to methods to minimize this waste. A prototype DSS was designed utilizing historical data at the University of Alabama. The design proposes a framework that integrates BIM with advanced analytical methods, within the DSS, to reduce the impact of construction waste materials. The current status of development of the prototype DSS, and future path forward, are discussed.

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### 1. NATURE OF THE PROBLEM

Construction and demolition (C&D) materials constitute a significant waste stream in the United States (EPA, 2018). Millions of construction projects are conducted each year around the world, which generate tremendous volumes of construction waste and associated environmental problems. Typical components in C&D waste are inert materials (e.g., concrete, and bricks.), which are generally believed to do little damage to the environment beyond additional landfill volume (EPD, 2012). If some hazardous components (e.g. asbestos) are not disposed of properly, further negative impacts will be made on the environment. However, even relatively benign construction waste yields additional landfill volume is not a trivial consideration. In the latest report by the Environmental Protection Agency (2018), 548 million tons of C&D debris were generated. Concrete comprised the largest portion which is 70%, followed by asphalt concrete at 15%, C&D wood products were 7%, and the other C&D components added to 8% of the total C&D debris generation in 2015. According to the data in the report, over 90% (around 519 million tons) of total C&D debris were generated from demolition, while construction represents less than 10% (EPA, 2018).

### **1.1. Importance Of The Problem**

The need to reduce construction waste is rising with the increasing number of construction projects worldwide. This need is strongly supported by the growing emphasis on implementing sustainable construction practices. Outside of these sustainable goals, there are three important but contradictory objectives in an ordinary building construction project – time, quality, and cost, which are usually difficult for project managers to optimize (Ashokkumar and Varghese, 2018). To most construction companies, the cost generated by managing construction waste decreases the profits. Significant extra cost could be generated from inappropriate handling and insufficient recycling of construction waste. Previous studies indicate that construction companies can benefit from reduced waste generation by lower disposal costs and lower purchasing costs of virgin materials (Bossink and Brouwers, 1996). Waste minimization has become an important area of concern in the construction industry (Dajadian and Koch, 2014). However, even though construction stakeholders are paying increasingly more attention to the negative impact to the environment caused by construction waste, the knowledge of the origins and distribution of this construction waste is very limited. Moreover, studies focused on developing and applying effective decision support tools within this domain are scarce. Therefore, it is essential that researchers develop useful tools that incorporates advances in information technology to support C&D minimization.

## **2. LITERATURE REVIEW**

C&D waste minimization aims to apply techniques which can avoid, eliminate or reduce waste at its source. Previous research on construction waste minimization tends to focus on studying its origins (Osmani, 2012). Numerous studies state that design changes during the construction stage, resulting in rework, are major causes of waste generation (Liu et al, 2015). Al-Hajj and Hamani (2011) combined construction projects observation results with literature findings to design a questionnaire for assessing the main causes of material waste and waste minimization measures. The study posits that the main causes of material waste in the United Arab Emirates (UAE) are rework and variations, lack of awareness, and excessive off-cuts resulting from poor design; while staff training, adequate storage, and just- in time delivery of materials were the most frequent used minimization measures. Twenty-four interviews investigating the underlying origins, causes and sources of waste across all project life cycle stages were conducted by Osmani (2013). Results From the study indicates that the lack of embedding waste reduction requirements and expectation in contractual documents and contractor briefings and designers lack of understanding of waste origins are primary causes of waste generation in the built industry. Yuan (2013) identified 30 key indicators affecting the overall effectiveness of C&D waste management, he developed a C&D management effectiveness assessment framework through analyzing the data from literature review and semi-structured interviews.

Researchers have also adopted emerging technologies as a tool to enhance C&D waste minimization. For instance, Chen et al. (2002) implemented bar-coding technology to reduce construction waste in a group-based incentive reward program to encourage workers to minimize avoidable wastes of construction materials by rewarding them according to the amounts and values of materials they saved. Li et al. (2005) integrated Global Positioning System (GPS) and Geographical Information System (GIS) technology for reducing construction waste and improving construction efficiency. Similarly, a combined GIS and Life Cycle Assessment (LCA) model was developed for construction resource and waste management using site-specific data (Blengini and Garbarino, 2010). Moreover, the advent of Building Information Modeling (BIM) in the construction industry has provided more opportunities to reduce C&D waste.

### **2.1. Relevance of BIM**

BIM has been used in many aspects of construction. BIM represents the process of development and use of a digital computer building model to simulate and manage the planning, design, construction, and operation of a building facility (Ashokkumar and Varghese, 2018). BIM techniques enable both contractors and customers to check the constructability in the design stage before actual construction. As a visual

database of building components, BIM can provide accurate and automated quantification, and assist in significantly reducing variability in cost estimates. This significantly reduces errors and uncertainties that could occur in subsequent stages. BIM also provides an efficient way to manage scheduling, cost estimating, design, communication and other important components in a construction project (Bryde et al., 2013).

BIM methods, at present, have not been used significantly for construction waste minimization (Liu et al, 2015). In the previous research, BIM has indicated the potential to aid contractors and designers to minimize the construction and demolition wastes by planning waste control strategies. A BIM based system can extract material and volume information through the BIM model, then integrate the information for detailed waste estimation and planning (Cheng and Ma, 2013). There are still many challenges that exist in the current application of BIM in minimizing construction waste. Investigation of the literature implies that current BIM implementation in construction waste minimization is limited, with many systems only analyzing some specific aspects. Combining BIM with other complementary analytical techniques has the potential to yield improved decision-making tools for C&D waste minimization.

### **3. RESEARCH OBJECTIVE AND APPROACH**

University-related construction has many unique aspects compared to other construction applications. Public postsecondary construction has been decentralized since 1995, when most state universities and colleges have administrated their own construction program, with the direction provided by individual boards of trustees (BOT). Campus projects are funded from a variety of state and non-state sources, which dictate certain project aspects. Generally, all of the construction projects in a university need to be fitted within a predetermined campus master plan. Such campus master plans are based on assumptions about basic campus characteristics drawn from projections of long-range academic plans (Caruthers and Layzell, 1999). They outline building design and location, campus traffic patterns, utilities needed, and required land improvements or acquisitions.

Construction Administration (UACA), a department at the University of Alabama (UA), seeks to determine how to better support their responsibilities for construction in a public university environment. The objective of this research project is to develop a prototype DSS for quantification and reduction of construction material waste. UACA is aware of the total amount of construction material waste disposed of, and the associated disposal cost. However, they require more detailed visibility into the component volumes and costs, as a step toward material waste reduction.

“Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based system for management decision makers who deal with semi-structured problems” (Turban and Aronson, 2001). A DSS can effectively extend the decision makers’ capacity for representing and processing information while reaching solutions faster and with more reliability. Quite often, the solutions will be optimal with supporting evidence provided. However, the use of DSS is limited by the underlying mathematical model selected, the hardware/software platform selected, and the design itself. As a result, it may be intended for a very specific range of problems (Moynihan et al, 2006). The components of a DSS can generally be classified into the following distinct parts: (1) the data management system; (2) the model management system; (3) the user interface; and (4) the user(s) (Moynihan et al, 2006). The model management system is particularly important for the success of a decision making system. The model is mathematical in nature, usually consisting of a management science/operations research (MS/OR) algorithm.

### **4. PROPOSED FRAMEWORK**

Consistent with the traditional systems development life cycle (SDLC), accepted DSS development methodology identifies four primary phases: 1) data acquisition, 2) system design, 3) system construction, and 4) verification and validation (Turban and Aronson, 2001; Laudon and Laudon, 2013). According to the SDLC approach, the first step in DSS development consists of determining the key concepts and

relationships with respect to algorithms, parameters and system constraints (Huscroft et al, 2013). It involves the understanding of the underlying data and algorithms and their merging into the modelbase. This research utilized existing models that were obtained through the review of the relevant literature. It did not aim at developing new models since extensive research has already been done in this field, and further exhaustive experimentation would be required for formulation and validation of any new model. Thus, the research focused on developing a DSS using only proven theories and models. Using accepted SDLC techniques (Laudon and Laudon, 2013; Jacyna-Golda, 2013), a generalized proof-of-concept system is being developed and evaluated, as a basis for further refinement.

As an initial step, the conceptual design envisioned an overall DSS framework that integrates BIM with advanced analytical methods encompassing a waste management cost metric within a decision-making tool. Figure 1 shows the components of this conceptual framework. After considering a variety of criteria, particularly software availability, Microsoft Excel was selected as the modelbase for this DSS project. Several studies have successfully used Excel as a DSS modelbase (Li et al, 2004).

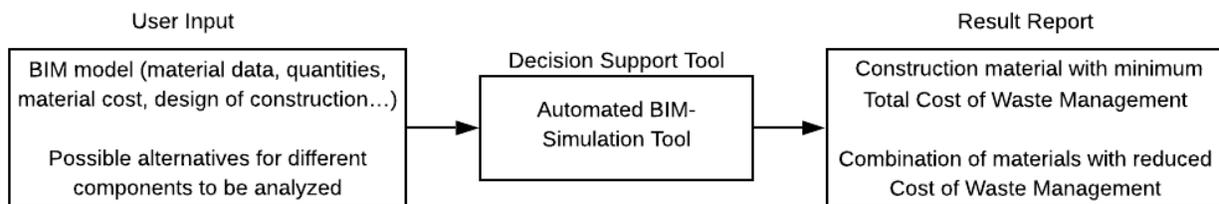
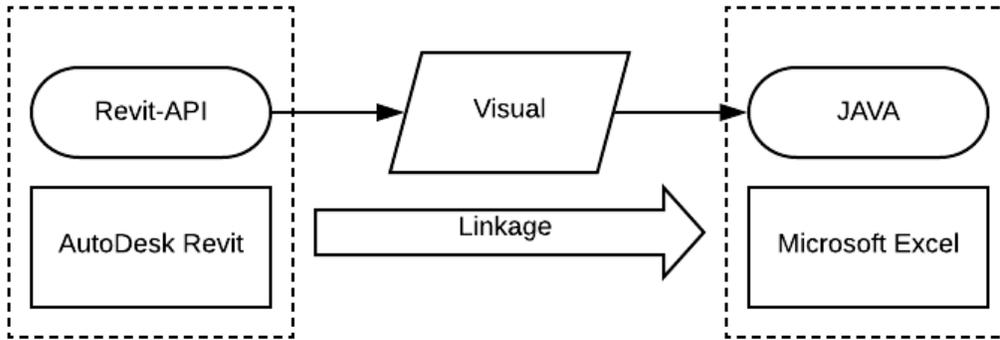


Figure 1. Components of conceptual design

#### 4.1. Current Status

The methodology used in the research was to create a linkage between the BIM software model and the decision-making model. There are a number of commercially-available software packages for BIM, such as Autodesk, Bentley Systems, Nemetschek and Graphisoft (Ashokkumar and Varghese, 2018). For this research, Autodesk Revit was used to create the BIM models, which were provided by UACA. Autodesk Revit is capable of modeling building components, analyzing and simulating systems and structures, and iterating designs (Autodesk, 2018). Different material options and quantities of each component can be obtained from Revit. Revit then exports the data regarding different materials used in the projects by UACA Construction Administration, such as concrete, wood, steel, and bricks. This data will be used to determine the forecast usage value for each type of material.

The methodology employed in this research is to move the data from a BIM software model to the decision tool by creating a linkage between Autodesk’s Revit and Microsoft Excel. This one-way BIM – Decision-making link automatically populates the variables in the Excel spreadsheet with data from the Revit model, as depicted in Figure 2, and is accomplished through Java and Visual Basic applications. The data is output from the BIM model via its API into a Visual Basic or C++ external application. Shen (2017) used a similar process to create and customize a near-miss data visualization tool for enhancing construction safety. In his study, an algorithm was used to compute the optimized tower crane location through Revit, the text file and MATLAB (Shen, 2017).



**Figure 2. Linkage between BIM and decision support tool**

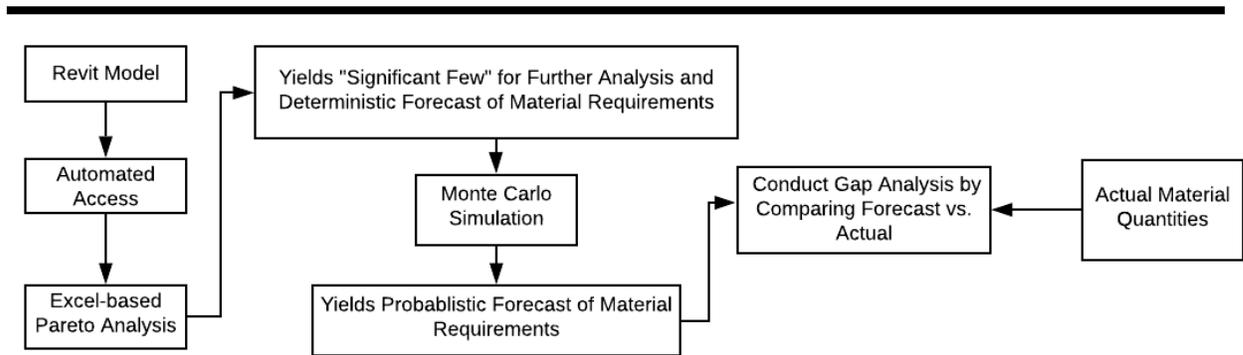
A Revit model of a recent construction project was provided by UACA. The construction components were analyzed by using the Pareto Analysis statistical technique. Pareto Analysis is a method of ranking categorical names by the relative frequency of the categories in some data. The most frequent category appears first, followed by the second most frequent, and so on. Review of Pareto bar charts indicated the Pareto Principle “(80-20 Rule”) at work: in general, about 20% of the categories are responsible for 80% of the material volume. Pareto Analysis is a decision-making type statistical tool which can help select the few categories producing the most significant overall effect (Aibinu & Odeyinka, 2006). Applying Pareto Analysis to construction material usage of a project determined the component types (here, masonry, metal, and other) with the relatively highest usage. A second iteration of Pareto Analysis within these three general categories, and with guidance from UACA, indicated subsequent focus should be directed to the following subcategories: bricks, blocks and other masonry; metal studs for walls; acoustic ceiling tiles, and drywall.

#### 4.2. Path Forward

Microsoft Excel can calculate the total quantities required for each of the targeted subcategories. This represents a deterministic forecast of material requirements. In practice, material usage may vary somewhat (e.g. due to worker skill/experience, and conditions at the jobsite). The application of Monte Carlo simulation is planned to take into consideration this uncertainty in material usage. Monte Carlo simulation is a statistical analysis tool which is based on the use of random sampling and probability statistics to investigate problems (Marzouk et al, 2018). Marzouk et al (2018) used it to evaluate the life cycle cost for alternative materials taking into consideration uncertainty in costs for sustainable buildings. In this research, an Excel-based Monte-Carlo simulation will be used to calculate a probabilistic forecast of material required.

Actual material quantities purchased for the construction project, and their respective costs, are available from project historical records. A gap analysis will be conducted by comparing the two data sets. The difference between the forecast and actual volumes represents the material waste by category. A functional flow diagram of the DSS processing logic is portrayed in Figure 3.

The total waste charging fee for each of the different types of construction materials will also be calculated. Based on the research of Yuan et al. (2010), *the total cost of waste management consists of cost of collecting, cost of sorting, cost of reuse, cost of recycling, cost of disposal and transportation cost*. These six costs will be used to calculate the total construction waste management cost for each material type. The supporting data for the waste management cost of different C&D waste components will be obtained from past University projects to the extent possible. Alternatively, sources from the existing literature (e.g. RS Means) or official statistics reported by the EPA will be investigated. A survey may also be conducted to collect the data of six cost variables.



**Figure 3. Functional flow diagram of DSS processing logic**

Verification and validation are important steps in ensuring the quality and reliability of the DSS (Turban and Aronson, 2001). Verification confirms that the system is robust and error-free. Consistent with the procedure discussed by Laudon and Laudon (2013), unit tests will be conducted on the individual components of the DSS. System tests will then be executed to verify the correctness of overall system functionalities. Every test case and the corresponding result will be recorded in a test case form. When a result indicates a failure, the case will be analyzed and the system redesigned to correct the problem. After any modification, the system will be retested using the same test case. Such procedures will be continued until all test cases yield positive results.

As suggested by the International Standards Committee (2005), in their ISO 12207 document, validation denotes checking whether the final product fulfills specific intended use. Validation techniques can be broadly classified into two categories: qualitative validation and quantitative validation (Turban and Aronson, 2001). Qualitative validation, which is further classified into face validation and predictive validation, will be the validation technique to be utilized for this project. Face validation is a simple, qualitative fairly informal validation technique. The system will be evaluated at face value by experts from the problem domain, project members and users familiar with university construction projects. The prototype DSS will also be validated through their review of the system documentation and functionality. Suggestions for later enhancement will be noted.

## 5. CONCLUSIONS AND FUTURE RESEARCH

A clear quantification of the constituents of construction waste is the first step toward their reduction. Further research is envisioned to link the Revit model to the construction project's Work Breakdown Structure (WBS). The WBS identifies individual tasks within the project, as well as the relationship between them. Subsequent application of Pareto Analysis and Monte Carlo simulation, by the Excel decision tool, will identify those tasks responsible for the largest share of construction waste, and where management attention should be focused for waste reduction.

## 6. ACKNOWLEDGEMENTS

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# Critical Factors Affecting Enrollment, Performance, and Retention & Graduation Rates of Construction Management Undergraduate Students

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**Abstract:** The shortage of construction manager and skilled construction workers is becoming one of the country's great-unsolved problems as the economic expansion has continued in USA because of various reasons, such as low students' enrollment in the construction management and related programs, poor academic performance of students, and low retention and graduation rates of students in US universities. Therefore, it is essential to identify possible factors that directly and indirectly influence students' enrollment, academic performance, and retention and graduation rates of students. By conducting an extensive literature review, this paper reports various factors that influence students' enrollment, academic performance, retention & graduation rates, and classifies these factors in the relevant clusters, such as university factors (academic & organizational factors), student factors, and family & social factors. In addition, this paper maps those factors in various clusters by applying the affinity grouping technique. Revelation of such factors can provide valuable insights to educators and students. It also helps to educators to formulate effective teaching strategies to achieve maximum outcomes. Moreover, the finding of this research not only contributes to the body of knowledge but also develop a foundation for designing the systematic strategy for effective educational policy in the country and addresses the lack of policy or strategy to resolve the skilled workforce shortage issues.

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## 1. INTRODUCTION

With the improvement in the economy after recession, US Construction industry is growing and becoming one of the largest industries with expenditures reaching over 1,293 billion U.S. dollars (Wang, 2019). According to Bureau of Labor Statistics (BLS, 2019), employment of construction managers is projected to grow 10 percent from 2018 to 2028, which is faster than the average for all occupations. Similarly, there are huge demand of construction skilled workforce in various positions in the construction industry. The U.S. Census Bureau projects that the number of new jobs in construction industries will rise by 747,600 jobs between 2016 and 2026, which is about 11% growth. Meanwhile, the construction laborer shortage is becoming one of the country's great-unsolved problems as the economic expansion has continued. In this scenario, there is a big concern that "are all construction industry and academic sectors taking serious steps to resolve this issue?" Are they heading towards right direction to resolve this workforce shortage issue?

Certainly, some industry associations have identified this issue and have started collaboration with academic sectors to improve the number of graduates who are their future employees. Associated General Contractors Massachusetts (AGC-MA) and some other associations are already inline in this collaboration with universities in Massachusetts. AGC of America released a workforce development plan in 2014 to address this workforce shortage issue by preparing the next generation of skilled construction workers (Thompson, 2019). On the contrary, the number of students' enrollment, academic performance, and retention and the graduation rates in Construction Management program in most of USA universities are decreasing because of various seen and unseen factors. Revelation of these factors are critical in academic

as well as industry sectors because of their direct or indirect influences in the workforce shortage issue. Therefore, it is necessary to identify factors influencing students' enrollment, academic performance, and retention and graduation rates.

This paper reviews the literatures depicting what factors are critical to academic performance and graduation rate and why they play significant role in the preparation of educational strategy. After thorough investigation, author classifies and maps those factors into various clusters, such as university factors, student factors, and family & social factors. In addition, this research also uncover what factors are critical for students' enrollment and retention, selection of construction management major, and their performance in construction management major. The research finding contributes in the development of the systematic strategy for effective educational policy in the country. It also helps to identify and to address the lack of policy or strategy to resolve the workforce shortage issues.

## 2. RESEARCH FRAMEWORK

As today's Construction Management students are valuable workforce for tomorrow's construction industry, it is essential to assure that these students get required knowledge & skills and they perform well on study. The performance of students are influenced by various factors and the study of these factors are critical in developing effective teaching strategies and educational policy. Therefore, author conducted an extensive literature reviews by reviewing journal and peer-reviewed conference papers, books, and relevant documents. This paper extracted lists of factors influencing students' enrollment, academic performance, retention rate, and graduation rate from the following publications.

- Journal of Construction Education
- Journal of Professional Issues in Engineering Education and Practice
- Associated Schools of Construction (ASC) conference publications
- ASCE Construction Research Congress publications
- ASCE Leadership and Management in Engineering
- International Journal of Recent Research and Applied Studies
- Journal of Education and Practice
- Hindawi Education Research International
- Journal of International Students
- International Journal of Scientific Research and Engineering Development
- British Journal of Education
- International Journal of the Constructed Environment
- American Society for Engineering Education
- American Journal of Educational Research, and
- International Journal of Project Management (Elsevier)

Figure 1 shows various stages involved in this research. The author listed identified factors from literature reviews in the excel spreadsheet under three major topics discussed above which are: (i) factors affecting students' enrollment, (ii) factors affecting academic performance, and (iii) factors affecting retention and graduation rates. Then, those factors were classified into manageable groups by applying the affinity grouping technique, which creates and clusters factors into categories on the basis of their similarity. For example, ranking and reputation, location and accessibility of university, availability of infrastructures and labs, affordable fees, financial aid, and scholarship availability, competent faculty, extracurricular activities (students clubs activities), career opportunity (internships and jobs), academic advising & tutor service, hands-on activities, peer group, university learning environment, class size, effective teaching and training method, appropriate course load, and university management and staffs (Durdyev & Ihtiyar, 2019; Gregory 2014; Keller, 2012; Ostadalimakhmalbaf et al., 2019) are relevant to academic and organizational

factors, which are combined and classified into university factors. Family income and financial support, family crisis, motivation for learning or learning environment at home or in the society are family and society related factors (Yousefi, 2010). Lack of interest in a course, lack of concentration on study, lack of time management, fear & anxiety during exam, bad attitude towards school, lack of desire & motivation, laziness or apathy, and lack of decision & determination (Crosnoe et al., 2004; Koch, Greenan, & Newton, 2009; Olatunji et al., 2016; Osuizugbo, 2019) are some examples of student’s psychological and behavioral factors, which are considered as student factors. After classification, these factors were mapped. A pilot study was conducted to assess this framework (Figure 1) and compared the results with outcomes from literature reviews.

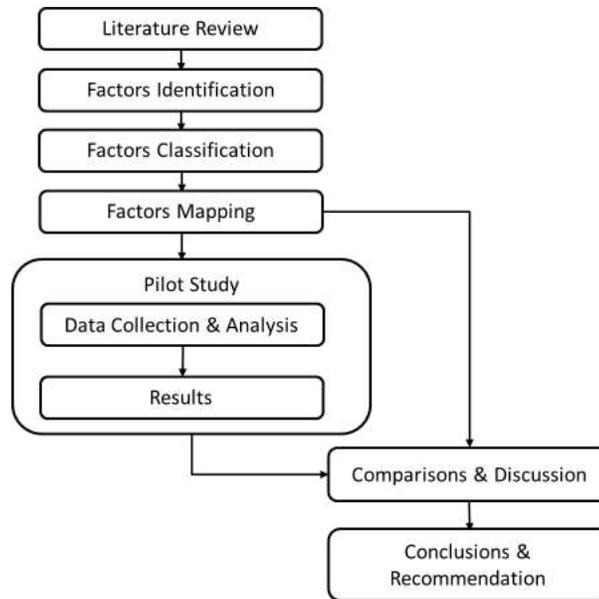


Figure 1. Research framework

### 3. PILOT STUDY

Though this research primarily relies upon an extensive literature reviews, the author further conducted a pilot study to test the research framework and also to determine influence of these factors on each affinity group. A survey questionnaire set was designed, which is explained in section 3.1. Data was collected and analyzed. The results from this pilot study was compared with outcomes from the literature reviews to evaluate and validate the research framework and outcomes from the research.

#### 3.1 Questionnaire Design

Based on the expert opinions and discussion, a questionnaire survey sheet was designed, where 24 factors affecting students’ enrollment, 53 factors affecting academic performance of students, and 21 factors affecting students’ retention and graduation rates under appropriate affinity groups were listed as per clusters discussed above. The questionnaire was structured mainly in three sections. In first section, the respondents were asked to rank the factors affecting students’ enrollment in construction management program on a 5-point Likert Scale; 1 being “strongly disagree” and 5 being “strongly agree.” In the second section, they were asked to rank the factors affecting academic performance of students on same 5-point Likert Scale. In the third section, they were asked to rank the factors affecting students’ retention and graduation rates. The justification for using a 5-point Likert scale type question is the fact that it is well

recognized as the most appropriate instrument for obtaining information about respondents’ attitudes and perceptions or analyzing particular attributes (Baker, 2003; Sekeran, 2000).

### 3.2 Questionnaire Sampling

The questionnaire surveys were completed in a paper format because it is just a pilot study and the focus group for this initial survey were Fitchburg State University students and faculty. A total of 65 questionnaire sets were distributed in Engineering Technology Department. Most of respondents were Construction Management students. Out of 65, only 42 validated data were analyzed for this study which is about 64.62%.

### 3.3 Data Analysis and Results

As described above, the respondents were asked to rate the listed factors affecting enrollment, academic performance, retention rate, and graduation rate on a scale of 1 to 5. The frequencies for each factor from overall respondents are listed in Tables 2, 3, and 4. These scores were then transformed to Relative Importance Index (RII) based on the formula as shown in Eq. 1 (Kometa et al., 1994; Tam et al., 2000) to determine the relative of the factors.

$$[1] \text{ Relative importance index (RII)} = \frac{\sum W}{AN}$$

Where, W is the weightage given to each factor by the respondent, ranging from 1 to 5 likert scale, A is the highest weightage (5 in the study), and N is the total number of samples. The RII ranges from 0 to 1, closer to 1 being the significant (Tam et al., 2000). Table 2 shows the RII values based on overall responses (42 respondents), following Eq. 1, and based upon each identified factors. Then, those factors were ranked based upon RII values.

**Table 1. University Related Factors Affecting Students’ Enrollment in CM Program**

University Factors (Academic & Organizational Factors)	Overall Frequency					Overall	
	1	2	3	4	5	RII	Rank
Career opportunity (Internships & jobs)	0	2	4	24	12	0.819	1
Affordable fees, financial aid, & scholarship	0	1	6	26	9	0.804	2
Ranking & reputation	1	4	9	12	16	0.781	3
Availability of infrastructures & labs	0	5	10	12	15	0.776	4
Competent faculty	0	4	12	12	14	0.771	5
Location & accessibility	2	1	7	25	7	0.762	6
Hands-on project activities	0	0	16	20	6	0.752	7
Peer recommendation	0	3	14	16	9	0.748	8
Extracurricular activities	1	7	9	18	7	0.709	9

This paper reports the data analysis and results for the university related factors that affect: (i) students’ enrollment in construction management program, (ii) students’ academic performance in construction management program, and (iii) students’ retention and graduation rates in construction management program. Similar procedures were adopted for other clusters. Nine major university related factors were identified which influence students’ enrollment in construction management program. Among them, career opportunity was ranked first as shown in Table 2. It means students enroll CM program if they see career opportunity, such as job growth, job demand, and internships availability in the construction industry. Affordable fees, financial aid, & scholarship availability and ranking & reputation of program and university are also major factors for the selection of university by students which are ranked second and

third, respectively as shown in Table 2.

**Table 2. Factors Affecting Students’ Academic Performance in CM Program**

University Factors (Academic & Organizational Factors)	Overall Frequency					Overall	
	1	2	3	4	5	RII	Rank
Competent faculty	0	1	12	14	15	0.805	1
Effective teaching and training method	1	1	6	24	10	0.795	2
University learning environment	0	1	8	25	8	0.790	3
Availability of infrastructures and labs	1	3	10	14	14	0.776	4
Appropriate course load	0	4	12	12	14	0.771	5
Class size	0	3	16	8	15	0.767	6
Academic advising & Tutor service	3	0	6	26	7	0.762	7
Peer group	0	0	16	19	7	0.757	8
Career opportunity (internships, jobs)	0	5	10	19	8	0.743	9
Hands-on activities	3	4	21	5	9	0.662	10

As shown in Table 3, ten major university related factors that affect students’ academic performance in construction management program were identified. The data analysis result shows that students’ academic performance mainly depends upon faculty competency and effectiveness in teaching and training method, which are ranked first and second as shown in Table 3.

**Table 3. University Related Factors Affecting Retention & Graduation Rates of Students**

University Factors (Academic & Organizational Factors)	Overall Frequency					Overall	
	1	2	3	4	5	RII	Rank
University learning environment	0	0	9	16	17	0.838	1
Competent faculty	0	0	8	20	14	0.829	2
Affordable fees, financial aid, & scholarship	0	2	3	25	12	0.824	3
Availability of infrastructures and labs	0	5	9	12	16	0.786	4
Career opportunity (internships & jobs)	0	5	9	20	8	0.748	5
Hands-on project activities	0	0	22	11	9	0.738	6
Ranking & reputation	2	5	3	28	4	0.729	7
Extracurricular activities	0	0	20	18	4	0.724	8
Location & accessibility	0	7	10	21	4	0.705	9
Peer group	2	6	14	12	8	0.686	10

Table 4 shows the university related factors that affect the retention and graduation rates of student. This study shows that students will retain at same university and graduate from that university if they find a good learning environment and competent faculty. If students receive scholarships and if university’s fees are affordable, it also helps to retain students at university. This paper only reports university related factors that affect students’ enrollment in CM program, academic performance of students in CM program, and students’ retention and graduation rates in tabular format. Similar approaches are implemented for other clusters or classified factors.

Once overall ranking of these factors were determined (shown in Tables 2, 3, & 4), these university related factors were mapped as shown in Table 5. It compares the factors mapping from literature reviews

with pilot study results. It shows that availability of infrastructures and lab, competent faculty, career opportunity, hands-on activities, and peer group recommendations are overlapped important factors that influence students' enrollment, academic performance, retention, and graduation rates in CM program. This finding indicates that university or academic institutes should give priority on these factors to improve students' enrollment, academic performance, and retention & graduation rates. For example, students do not prefer to enroll in such a university where there is lack of infrastructures and laboratory facilities. Also, research shows that most of the CM students prefer hands-on activities in their curriculum.

Similarly, student factors, family and social factors that influence students' enrollment, students' academic performance, students' retention & graduation rates in CM program are identified and mapped.

**Table 4. Comparison of University Related Factors Mapping and Pilot Study Results**

University Factors (Academic & Organizational Factors)	Ranking of Factors Affecting Students' Enrollment	Ranking of Factors Affecting Students' Academic Performance	Ranking of Factors Affecting Students' Retention & Graduation Rates
Ranking & reputation	3		7
Accessibility and location	6		9
Availability of infrastructures & labs	4	4	4
Affordable fees, scholarships, & financial aid	2		3
Competent faculty	5	1	2
Extracurricular activities	9		8
Career opportunity (internships, jobs)	1	9	5
Academic advising & tutor service		7	
Hands-on activities	7	10	6
Peer group recommendation	8	8	10
University learning environment		3	1
Class size		6	
Effective teaching & training		2	
Appropriate course load		5	

#### 4. CONCLUSIONS

The construction workers shortage is becoming one of the country's great-unsolved problems as the economic expansion has continued. In such a scenario, this paper brought the potential reasons of workforce shortage in construction industry for discussion. Some of them are: low students' enrollment in CM and related programs, poor academic performance of students, low retention rate, low graduation rates, lack of training, and lack of resources and funding in construction industry for teaching and training to their construction employees. To address this critical issue, it is essential to carefully review how to improve students' enrollment, performance, and retention & graduation rates in CM program, which ultimately impact on the workforce production. This paper presented a framework to conduct the research on various factors affecting students' enrollment, academic performance, students' retention, and graduation rates in

CM program. After identifying factors, those factors were classified and mapped under appropriate affinity groups. A pilot study was conducted to test the research framework. Future opportunities aside, this research concludes that the framework described herein represent a successful first step in mapping these factors. Author will present the extended study for other factors with the large population in future publication. This research provides valuable insights to educators and students which helps to educators to formulate effective teaching strategies to achieve maximum outcomes.

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# Using SAE-Baja Project In Attracting And Empowering Women In Engineering/Technology: A Case Of Success At Northern Kentucky University (NKU) And Cincinnati State Technical And Community College (CSTCC)

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**Abstract:** The literature shows that many efforts have been made to draw female students to STEM in general and engineering careers in particular. The importance of ensuring that engineering is a gender-neutral field and addressing the existing obstacles for females in the field are well documented. The objective of this report is to chronicle the method by which a student organization, such as Baja SAE Club, can be used as a catalyst for the involvement and empowerment of women in engineering and higher education. Additionally, the report highlights the collaborative efforts between the University and the local community college and the effectiveness of this collaboration in strengthening this cause.

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## 1. INTRODUCTION

Engineering professionals today are held to high standards and require a certain level of qualification to succeed in their respective industries. It is crucial for the training and education of future engineers to begin at an early age. This involves career aspirations made as early as elementary school, and continuing as the students' progress towards higher educational stages. To this end, many companies are also taking action to garner interest, promote involvement, and increase awareness for young girls in STEM and engineering fields. An example is Collins Aerospace, a unit of United Technologies and Raytheon Company, a leader in technologically advanced and intelligent solutions for the global aerospace and defense industry. They are "Redefining Futures" by inspiring girls and minorities to pursue opportunities in STEM by intentionally engaging with them at an early age. Their annual "Introduce a Girl to Engineering Day" event is held during National Engineers Week and is a movement to help young girls recognize their place in engineering a better world. It is targeted towards middle school to junior high school aged girls. Studies show that interest in STEM amongst young girls is at its highest between the ages of 5 and 16, but tapers off significantly once girls enter high school. Post-event survey results from the 2019 event showed that respondents were 80% more likely to consider a career in Engineering [15]. As organizations and companies continue these efforts, it is crucial for educational establishments to set up similar initiatives as well.

The literature also shows that the challenge to attract female students to engineering is two-fold: attract and keep them in the engineering career paths, and assure that there are positions available in these fields for individuals with the right qualifications, regardless of their gender. Offering the opportunity to work on technical projects with a strong purpose provides additional motivation for the individual to stay in that field of work. One venue for multicultural experiences coupled with technical experiences for students is

through multi-disciplinary collegiate competitions such as the SAE International's Collegiate Design Series (CDS) competitions (or simply “Baja SAE Competition”).

## 2. WOMEN IN ENGINEERING

A study conducted by Robert Hart [1] shows that, before 1940, the employment of women in industry and engineering positions was negligible. The landscape of employment in the field of engineering was transformed after the onset of World War II, when severe shortages in the number of skilled male workers served as a catalyst for the consideration of equally skilled women in the field. The employment rates of females in the field increased from 10.5% in 1939 to 35.2% by 1943. Due to the temporary nature of these wartime contracts and the return of the male professionals from the frontlines, a reduction in the female workforce employment rate was seen, with a reduction from 35.2% in 1943 to 20.9% by 1960. Despite this trend, a significant number of women retained their positions, thus making their participation permanently higher than it was prior to the war. This trend and the associated factors, such as wage considerations, labor laws, etc, are numerous and enable a better understanding of the current trends seen in the employment of women in engineering. These factors are not discussed further as they are beyond the scope of the objectives of the report.

Despite the ever-increasing importance of STEM and engineering in contemporary life, the number of women engineers remains low, at approximately 20% of the workforce, as depicted in Table 1.

**Table 1 Women's share of S&E bachelor's degrees, by field: 2000-2013**

Year	Physical sciences	Biological and agricultural sciences	Mathematics	Computer sciences	Psychology	Social sciences	Engineering
2000	40.8	55.8	47.8	28.0	76.5	54.2	20.5
2001	41.6	57.3	48.0	27.6	77.5	54.8	20.1
2002	42.7	58.6	46.9	27.5	77.5	54.8	20.9
2003	41.7	59.7	45.6	27.0	77.7	54.7	20.3
2004	42.2	60.1	45.9	25.1	77.8	54.5	20.5
2005	42.6	59.9	44.6	22.3	77.8	54.2	20.0
2006	42.2	59.8	44.9	20.7	77.4	53.7	19.5
2007	41.1	58.6	43.9	18.6	77.4	53.8	18.5
2008	41.1	58.2	43.9	17.7	77.1	53.5	18.5
2009	41.0	58.2	43.0	17.9	77.2	53.6	18.1
2010	40.9	57.8	43.1	18.2	77.1	53.7	18.4
2011	40.3	58.1	43.0	17.7	77.0	54.2	18.8
2012	40.2	58.1	43.1	18.2	76.7	54.7	19.2
2013	39.0	58.0	43.1	17.9	76.6	54.9	19.3

Source: Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, <http://webcaspar.nsf.gov>. Science and Engineering Indicators 2016

NOTE: Physical sciences include earth, atmospheric, and ocean sciences.

As opposed to the stagnation of trends seen in the employment of women in engineering, the trends seen in academia and other STEM fields, has been more encouraging. In academia, the number of female doctorate recipients in the fields of science and engineering increased by 84%, compared with 27% growth in the number of male awarded doctoral degrees. The percentage of doctorates awarded to women increased

from 33% in 1996 to 42% in 2009, and it has remained stable, since at this rate since that time [2]. The involvement of women in research and innovation is significant, as evidenced by the fact that between 2005 and 2015, an increase in the proportion of women researchers and of women with higher education degrees, remained higher than 50% in some European countries [3]. It is interesting to note that, according to the statistics presented by the National Girls Collaborative Project, career choices are made as early as elementary school, but the gender separation in STEM programs was more apparent at the undergraduate level [4]. This information is helpful in guiding when and where interventions that address and relieve obstacles to female involvement in STEM fields can best be applied.

### **3. STUDENT ORGANIZATIONS**

There are undeniable benefits for students who partake in university sponsored extra-curricular activities and programs. Programs have been found to enhance retention, in addition to the social integration. They also provide an experiential learning opportunity for students that increase interest in their chosen professional career.

According to Amiranzadeh et al. [5], the following factors are effective in involvement in student associations:

1. Student's personal characteristics: self-confidence, extraversion, emotional intelligence, self-efficacy, communication skills, eloquence skill, skill of understanding others
2. Structural Factors: Organizational culture, organizational climate, leadership
3. Background characteristics: Age, Sex, major
4. Other Factors: Family, school, peer
5. Environmental Factors: Political, social, economic, cultural, scientific

Students in these student organizations are the future leaders of the 21st Century who will have experiences related to Sustainable Development Goals even before graduating [6]

Female membership in discipline-specific student organizations appears to be related to involvement in other extra-curricular engineering activities. For example, those who have read an engineering listserv or newsletter, heard an engineering speaker outside of class, gone on an engineering field trip, had an engineering internship, and conducted research or worked for pay for a faculty member.

Additionally, women tend to be drawn to engineering projects that provide a benefit to society... Programs, student clubs, and classes were not designed to be particularly appealing to female students. Perhaps the reason some female students are being drawn into the engineering field is that they may find at the core of each of the programs a focus on engineering that is cutting edge, with an explicit social context and mission [7].

Women who participate in student organizations start the year more confident that engineering is the right major and career for them [8]. It is possible to identify a positive trend in student-driven clubs and organizations where female participants account for the majority of the overall participation. At the interdisciplinary D-Lab at MIT, which focuses on developing "technologies that improve the lives of people living in poverty," 74 percent of over 230 enrolled students this past year were women [9]. At Princeton, the student chapter of Engineers Without Borders has an executive board that is nearly 70 percent female, reflecting the overall club composition. Seventy percent of the university's student-run Sustainable Engineering and Development Scholars program is also female [7].

### **4. COOPERATION BETWEEN CINCINNATI STATE TECHNICAL COMMUNITY COLLEGE (CSTCC) AND NORTHERN KENTUCKY UNIVERSITY (NKU)**

SAE (Society of Automotive Engineers) Norse Baja, is a professional organization for students that are interested in the automotive field. SAE allows students the opportunity to apply skills learned in the classroom to real world applications through collegiate design competitions. These competitions provide irreplaceable hands on experience sought after by the automotive and aerospace manufacturers, suppliers,

and motorsport teams. This is an organization which includes students from various universities and community colleges. Cooperation between universities and community colleges have the potential to bring many benefits to students as both types of institutions bring different strengths to the table [10]. This report outlines the cooperation between NKU and CSTCC, in the form of pathway agreements that enable their A.S. degree graduates to transfer to NKU to obtain a B. S degree in different areas. Also, NKU and CSTCC have partnered in the development of curricular initiatives, such as the NKU's Mechatronics Engineering Technology program [11].

With so many of the CSTCC graduates transferring to NKU it would be only natural that NKU Norse Baja team have decided to collaborate with CSTCC Mechanical Engineering Technology program to combine resources in 2019-2020 academic year. The NKU Baja team now has over ten years of experience with Baja competitions, however this is the first year that CSTCC has attempted to compete in a Baja Competition. As it can be very difficult to create a new team, build a car, and get a competition in the first year with a new team, the collaboration between the two schools has been a critical factor in the success of the new CSTCC team. Veteran students from NKU have been eager to share their experiences and the CSTCC students additionally served as a valuable resource for manufacturing assistance while they learn from the more experienced NKU team. In the future, faculty advisors from both institutions will lead students in the process of building their vehicles separately, but with shared equipment and laboratory facilities, as well as collaborating in logistics. If a student decides to transfer to NKU upon completion of their AS degree at CSTCC, they may apply the acquired expertise to continue their progress on the NKU Baja project. This will allow students to develop better understanding of the various technical and managerial aspects related to the project as well as to future endeavors in their field of study. Students start at the beginning technical level and as they progress through their education, they will take on more advanced tasks including project and resource management responsibilities. Students involved benefit by interacting with other students and faculty from a different institution. While working closely with the NKU team, the CSTCC students will also gain familiarity with the NKU campus, students and instructors, making the transition to NKU a streamlined process.

There are multiple benefits realized from a collaboration such as this. Not only does this benefit students by creating a smooth transfer pathway and way to progress academically, it also allows the programs to pool resources. Each school has equipment and resources that the other may not have. Because Cincinnati State has a strong focus on manufacturing skills, they have created a well-equipped manufacturing laboratory with a wider array of equipment than NKU has. Where NKU team may be lacking some laboratory equipment they can provide extensive engineering knowledge along logistical support and assistance at the event. An example of collaboration for this year's car is the NKU team has constructed the frame in the CSTCC manufacturing lab. The CSTCC students helped construct the NKU frame receiving valuable guidance from the NKU team, thus learning in the process. Although the two teams' frames are completely different in design, getting experience is vital to develop any hands-on skill. Another example of pooling resources is sharing transportation to the event. With so much event experience the NKU team has everything needed for a Baja Competition, this can take a team years to procure. The CSTCC team is such a new team that they currently lack the equipment to get to the event and the equipment needed operate smoothly at an event. This year the NKU team has obtained a new trailer, large enough to fit the Baja vehicles from both teams, however the NKU team is lacking a truck able to pull the load. The CSTCC team has a truck that can safely haul the trailer allowing for both teams to benefit.

Thus far the collaboration between the two schools has been a great success for the teams and engineering programs as a whole. Both teams are growing and there is an increasing interest of students from all disciplines. Knowledge and skills are being shared and developed bi-directionally in a complementing way to each respective program and school. Due to the success of this collaboration the teams are planning a friendly race with other local teams to prepare for the next Baja competition.

## 5. CHRONICLE OF FEMALE STUDENT MEMBERS IN NORSE-BAJA AT NKU

From the inception of the Norse Baja team in 2010, there have been several key female team members involved each team annually. The following pictures shows some of the students that have been involved with Baja projects (Figures 1 to 6).



Figure 1. The NKU team at the 2019 midnight mayhem unsanctioned event, three of the students in this photo are recent transfer students from CSTCC



Figure 2. Welding the frame in 2010-2011 academic year team, with Captain seated in the frame



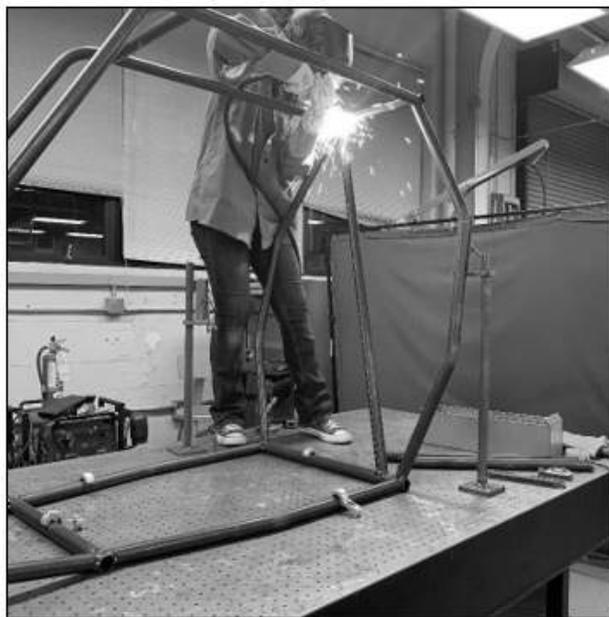
**Figure 3. Endurance race during 2014-2015 SAE Baja competition week**



**Figure 4. 2017-2018 SAE Baja competition structure and safety test**



**Figure 5. Female Baja participation in the Manufacturing lab and at Baja events**



**Figure 6. A female team member tack welding the 2019-2020 frame**

Currently (in 2019-2020 academic year), two of the key team members are female students. These include the team captain, and co-captain. Current team captain works full time at one of biggest manufacturers in the region and therefore brings in a wealth of current manufacturing experience. She has shown to be an excellent project manager guiding the team to adopt new and challenging innovations allowed by SAE. Example of this work is to design and build a 4-wheel drive version of the Buggy for the first time this year.

In a presentation by Dr. Carissa B. Schtuzman, Associate Vice President for Adult and Graduate Education at Thomas More University about role of women in manufacturing [12], she stated that a key to

earn a degree successfully is peer support. She also said women's way of working are not "Less Than" as they tend to:

- Solve problems collaboratively
- Focus on productive goals
- Prioritize tasks and manage time effectively
- Open to mentoring by other women or men
- Navigate the nontraditional environment in multiple ways

During the academic years since the inception of NKU SAE Norse Baja in 2010, our observation corroborates with the above findings. The exemplar attributes for women in Baja teams and in manufacturing careers in general is their willingness to:

- Do formal manual experiences that comes with the tasks at hand
- Tend to be self-reliant problem-solvers
- Exhibit high degree of mental and emotional toughness
- Demonstrate academic success while going through their academic careers

The goals in encouraging women involvement in the Baja project are:

- 1) Create a peer program that convene regularly
- 2) Utilizes training that results from their college experience
- 3) Ensure engagement and connection formally and informally
- 4) Create an inclusive culture by privileging and rewarding team members
- 5) Provide exemplar attributes in their search for jobs in industry and
- 6) Provide an internal leadership program that purposely include female students.

There is also anecdotal evidence of growing female participation and leadership in SAE Baja such as the viral hash tag: #girlsofbaja. This started as a fun photo taken by Cornell students and has now grown into a sort of movement in the Baja community. [13] It is not uncommon to see students and staff wearing "#girlsofbaja" t-shirts at events showing support for women in engineering.

## 6. CONCLUSION

Our goal at NKU is to attract more female students into Engineering Technology programs by encouraging them to work collaboratively in a project and utilize the key factors in the success of female students mentioned above. Experience in leadership roles shows that women's ability to collaborate and focus on certain areas are far greater than their male counterparts [14], therefore their participation in student projects like Norse-SAE Baja could take full advantage of those abilities toward the overall student success.

The current enrollment in the Engineering Technology programs is 217 students, from which only 11 are females (reference Table 2 and 3). Female students are still vastly underrepresented, but it is worthwhile to mention that a significant portion of them are involved with the SAE-Norse-Baja team, and all of them in leadership roles. We present this data in an effort to encourage further endeavors in promoting the involvement of females in the field of engineering.

**Table 2. Total Enrollment in Engineering Technology programs**

Academic Period	Specialization	Student Count
2019-2020 Spring	Electrical & Electronics Eng Tech Major	27
2019-2020 Spring	Electronics Engineering Tech Major	33
2019-2020 Spring	Mech & Manuf Engineering Tech Major	132
2019-2020 Spring	Mechatronics Engineering Tech Major	25
<b>Total</b>		<b>217</b>

Source: NKU Office of Institutional Research

**Table 3. Enrollment in Engineering Technology programs - Female Students**

Academic Period	Specialization	Student Count
2019-2020 Spring	Electrical & Electronics Eng Tech Major	1
2019-2020 Spring	Electronics Engineering Tech Major	1
2019-2020 Spring	Mech & Manuf Engineering Tech Major	7
2019-2020 Spring	Mechatronics Engineering Tech Major	2
<b>Total</b>		<b>11</b>

Source: NKU Office of Institutional Research

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## University-Industry Collaboration to Meet Criterion 7 of an ETAC Accredited Program

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**Abstract:** With budget shortfalls for education and lack of sufficient funds from grants, institutions are eager to reach collaboration with engineering-related organizations and industries in order to adequately provide current and relevant instructional resources. Institutions are required to demonstrate their support to programs by providing adequate classrooms, laboratories and equipment to enhance students' hands-on experiences and facilitate the attainment of student learning outcomes.

This paper provides a chronicle of how this cooperation was accomplished to may serve as a reference for institutions seeking additional support for their programs. It also provides examples of how the laboratories and equipment made possible through this collaboration can support engineering technology classes. This facilitates a potentially case-study like approach with discussion on the implementation following the guidelines and framework proposed by Yu et al [1].

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### 1. INTRODUCTION

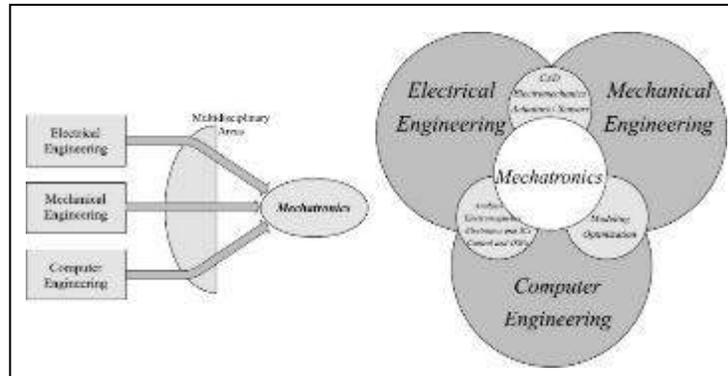
Founded in 1968, Northern Kentucky University (NKU) is a metropolitan university with approximately 14,000 students, located in Highland Heights, Kentucky, in the greater Cincinnati area. NKU currently offers the following Bachelor of Science degrees in Engineering Technology:

- Electrical and Electronics – EEET (formerly Electronics Engineering Technology – EET)
- Mechanical and Manufacturing - MMET
- Mechatronics – MET

The programs count on the support of local industry, who provide most of the students with co-op opportunities. The MMET and the EEET are long-standing programs at NKU. These programs have catered to the manufacturing industries in Northern Kentucky / Southern Ohio areas for more than two decades. Certificate programs can also be tailored to local employers, in order to fulfill specific gaps in the workforce. Processes of continuous improvement and assessment of course outcomes as well as students learning outcomes are embedded in the program, to address the extent to which the programs meet applicable ABET Criteria and policies for accreditation.

### 2. MECHATRONICS

The term mechatronics was first used in the late 1960s by a Japanese electric company to describe the engineering integration between mechanical and electrical systems. It is an integrated comprehensive study of electromechanical systems, integrating electrical, mechanical and computer engineering areas [2]. Mechatronics can be defined as the analysis, design, and integration of mechanics with electronics through intelligent computer control [3], as can be seen in Figure 1:



**Figure 1 - Mechatronics integrates electrical, mechanical and computer engineering. (Source: Lyshevski, Sergey E., *Mechatronics curriculum – retrospect and prospect (Mechatronics 12, 2002)*).**

A new Mechatronics Engineering Technology Bachelor of Science (BS) program has been developed and is being offered by NKU. A survey conducted among employers in the Northern Kentucky and Southern Ohio areas demonstrated very clearly the need of mechatronics professionals, as employers attempt to meet their capacity-constrained needs internally with programs in the form of in-house training; they also favor the adoption of formal education programs, in order to accelerate the rate by which those professionals became capable to carry out their tasks.

The program was approved by the Kentucky Council on Postsecondary Education in March 2017 and was made available in the university catalog for the Fall 2017/2018 academic year. A pathway agreement with the Cincinnati State Technical and Community College (CSTCC) was developed to facilitate transfers for students who graduated in the CSTCC Electromechanical Engineering Technology in Applied Science program [4] [5].

### 3. BUDGETARY CHALLENGES

Many, if not most, administrators in public higher education institutions struggle in states that are systematically reducing appropriations. The reasons for that are not in the scope of this paper.

A study conducted by the Center on Budget and Policy Priorities (CBPP) shows that the majority of states promoted a significant reduction in funding, since 2008 [6] (Figure 2). The same study shows that tuition has increased sharply during the same period, evidencing an attempt to offset the budget cuts, as shown in Figure 3:

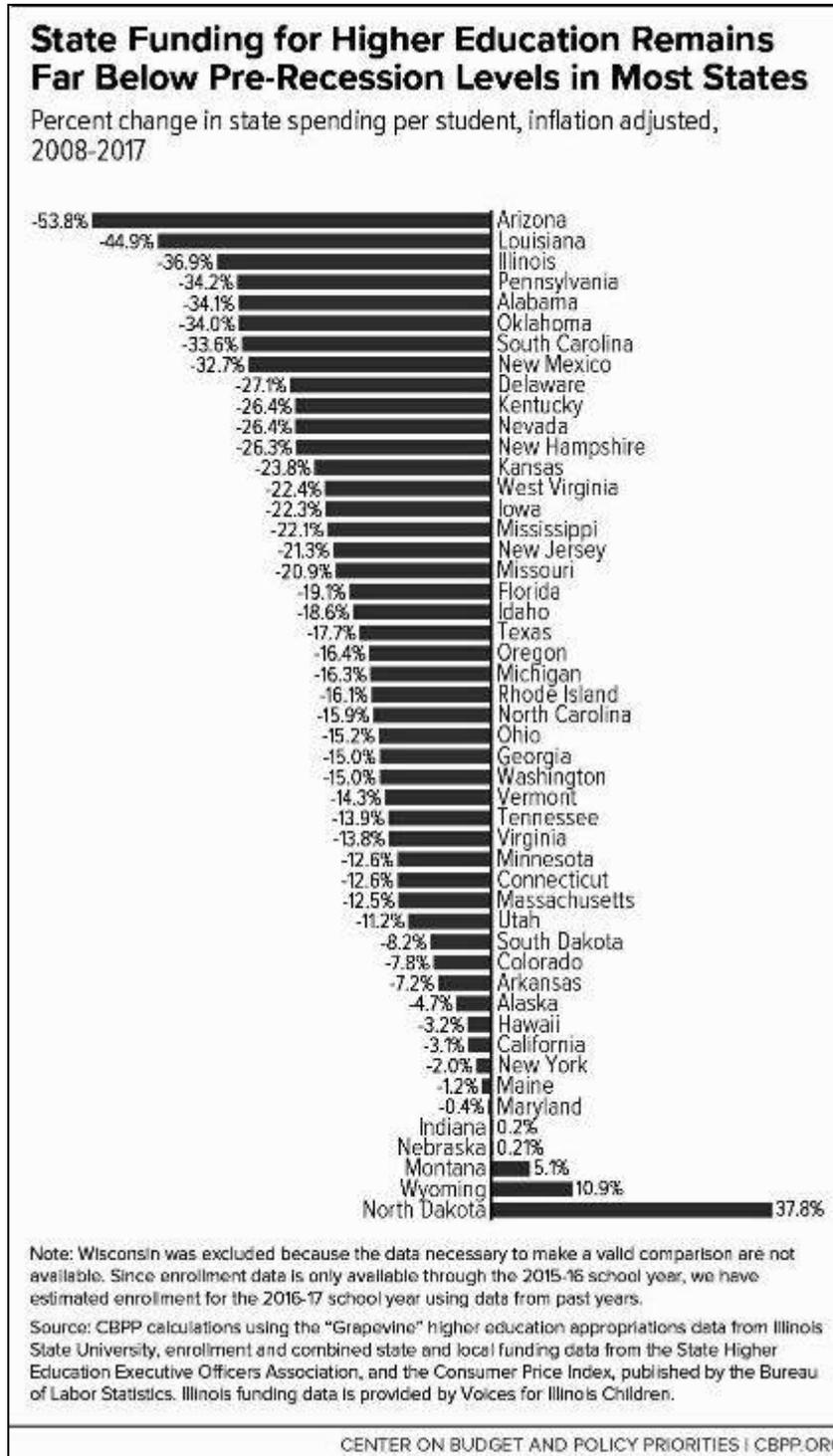
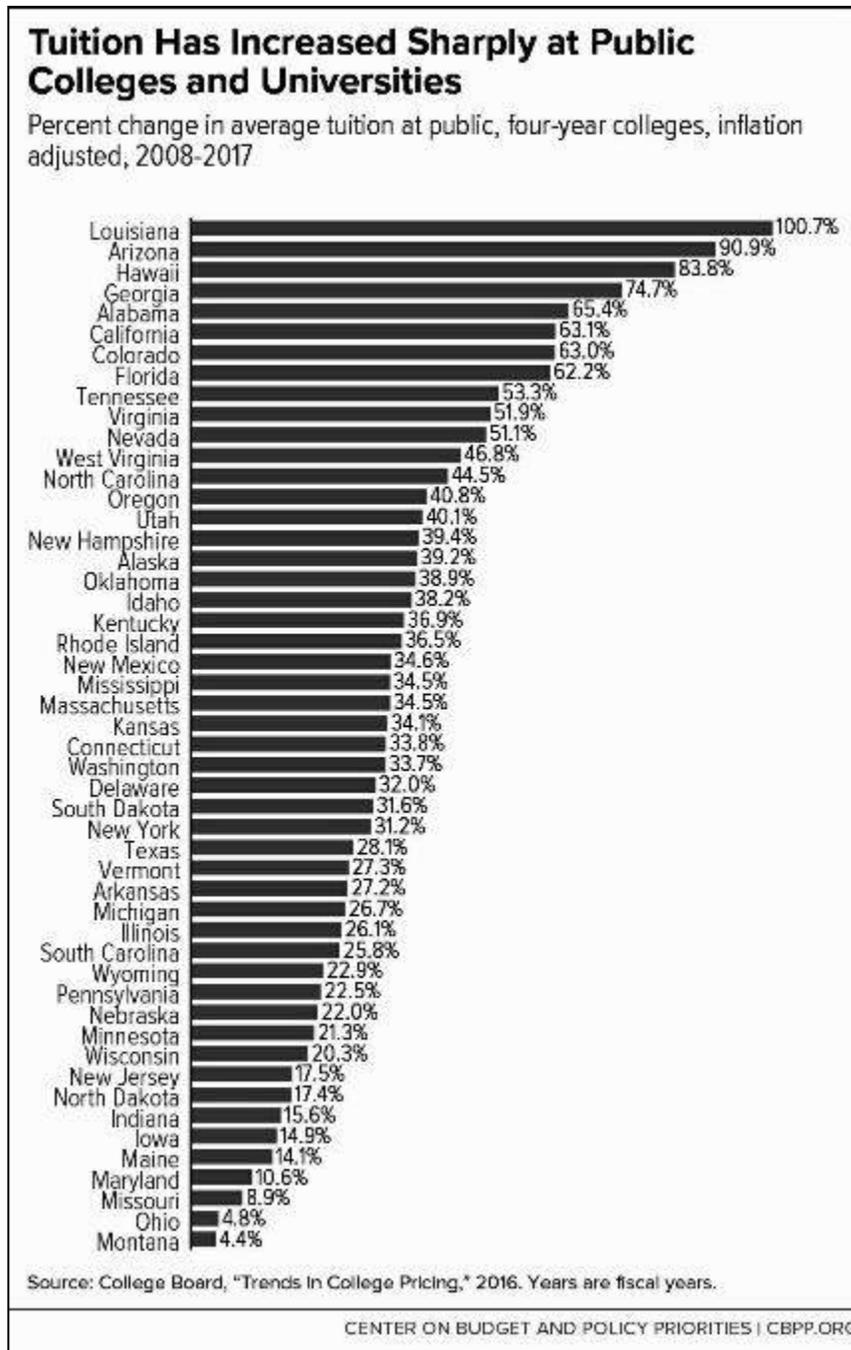


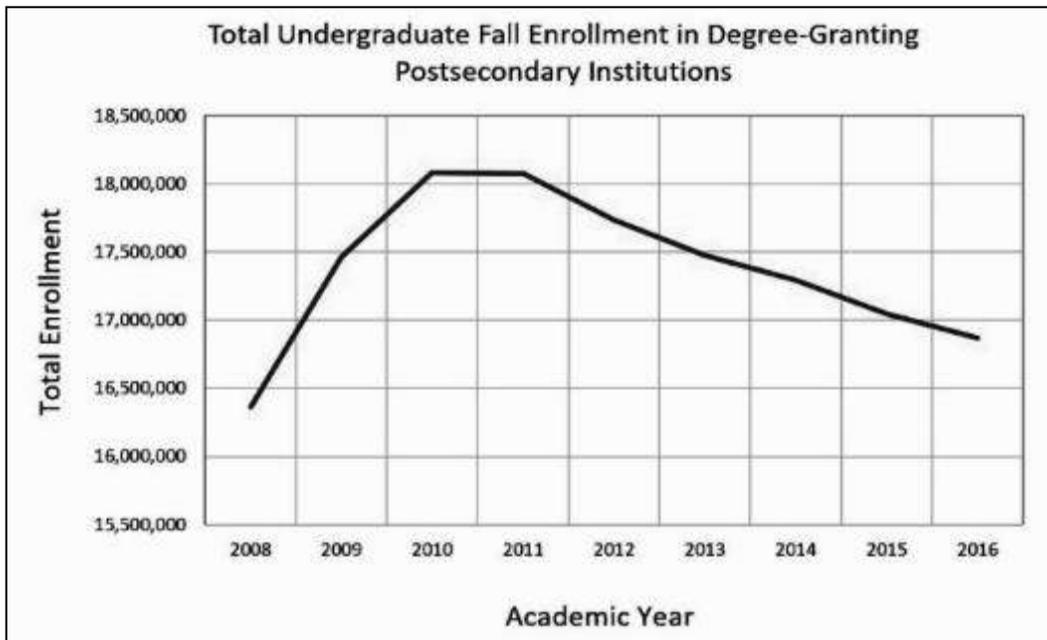
Figure 2 - State funding for higher education since 2008 - Source: This material was created by the Center on Budget and Policy Priorities ([www.cbpp.org](http://www.cbpp.org)).



**Figure 3 - State funding for higher education vs. tuition increase since 2008 - Source: This material was created by the Center on Budget and Policy Priorities (www.cbpp.org).**

However, tuition increases seemingly are unavoidable as many states or governing bodies impose caps on the institutions' freedom to establish them. Another factor to consider is the decrease in enrollment, which impairs attempts to offset budget cuts with tuition increases. It is important to notice that between the years of 2010 and 2017 the estimated growth in the U.S. population was approximately 5.5% [7]. National Center for Education Statistics (NCES) [8] data indicate a decrease in total enrollment in post-secondary education

institutions during the same period, as shown in Figure 4. The reasons for that decrease are not in the scope of this paper; however, the secular trend is important for strategic planning.



**Figure 4 - Total undergraduate fall enrollment in degree-granting postsecondary institutions. Source: NCES**

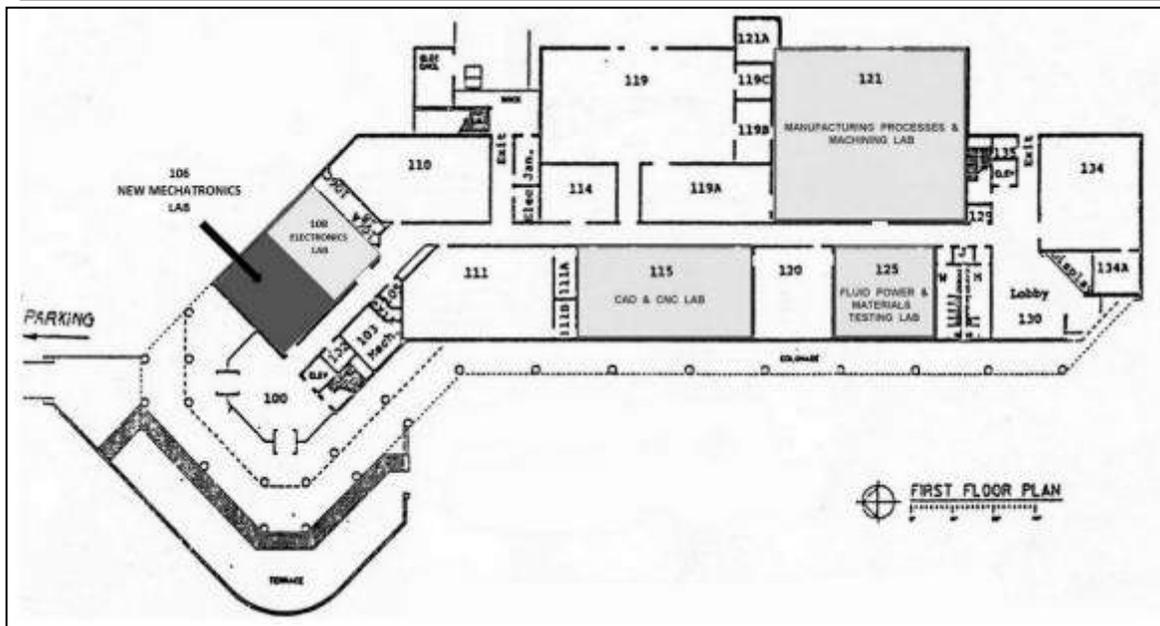
In this scenario, administrators have to face difficult decisions, involving prioritizing resources to face non-discretionary expenses (e.g., utilities, health insurance premiums paid by employers, and many others) in lieu of investment in educational equipment and facilities.

With budget shortfalls for education, and lack of sufficient funds generated by grants, some institutions are eager to reach collaboration with private-sector organizations. Institutions are required to show (among other aspects) their support to programs by providing adequate classrooms, laboratories and equipment to enhance students’ hands-on experiences to facilitate the attainment of student learning outcomes.

#### 4. ETAC GENERAL CRITERION 7 – FACILITIES

Accreditation Board for Engineering and Technology (ABET) has recognized the emerging importance of mechatronics engineering and has recently proposed specific evaluation criteria for “Mechatronics Engineering and similarly named programs” that are in the review process [9]. Nevertheless, the outcomes of the program are established and assessed through a process consistent with the current criteria and guidelines of ABET-ETAC [10] for accrediting engineering technology programs. These guidelines embrace all aspects in the program, and the ETAC General Criterion 7 [11] focus specifically in the facilities (and related resources) available to support it.

NKU Engineering Technology Programs (EGT) occupy 9 rooms on the second floor of the Business Center to accommodate the faculty and program’s administrative specialist’s offices. All laboratory classes are taught in the following rooms, all located in the first floor: BC108, 115, 117, 121, 125. The EGT also uses some conventional classrooms on an as-needed basis. The Business Center building floor plan (first floor is depicted in Figure 5.



**Figure 5 - BC building floor plan - New mechatronics laboratory location**

These facilities support the long established MMET and the EEET programs; however, the newly established Mechatronics Engineering Technology (MET) still lacks a dedicated automation laboratory.

## 5. LABORATORY IMPLEMENTATION AND IMPROVEMENT GUIDELINES

A solid understanding of multi-domain dynamic systems with accompanying modeling and analysis techniques is the key technical skills set that mechatronics engineers should master [12]. To support the classes in mechatronics systems, and to emphasize the correlation between different subjects (applied engineering and pure sciences) the implementation of new and/or improvement of existing facilities will follow the procedure adopted by Yu et al. [1] in designing each specific laboratory. The planning and implementation of the mechatronics laboratory should follow the following guidelines, which were adapted to the NKU context:

- The laboratory should be designed to support a set of experiments to enable application of the concepts presented in the lecture part of course.
- The laboratory should be designed to use equipment from world-class enterprises and leading and popular technology in the market to the maximum extent possible.
- Instead of just a demonstration or validation of learned theory, the laboratory equipment and devices should be developed to be as close as possible to the real-world industrial situations.
- The laboratory should have enough sets of instrumentation and components to provide each student with a significant hands-on experience.
- The laboratory should provide enough space and equipment so that teams of two to three students can work together on experiments or projects.
- The laboratory should be planned to be consistent with the orientation of the mechatronics program at the institution (e.g., NKU).

## 6. UNIVERSITY-PRIVATE-SECTOR COLLABORATION (UIC)

According to Liew et al. [13], UIC is largely reliant on the ability to identify the common denominators between the university and the industries that rely on the expertise and graduates on engineering-related programs. They will become the parameters that will be prioritized in the collaboration framework to ensure the

resources of both collaborators are sufficient. An opportunity was devised by Rockwell Automation, Inc. in the sense that students training in Rockwell’s equipment will likely be in decision-making positions few years after graduation, which may affect selection of equipment and systems for future needs.

The Allen-Bradley brand of programmable logic controllers (PLC) and automation systems [14] are owned by Rockwell Automation and it is widely adopted by industries that employ engineering graduates. To carry out this initiative a collaborative agreement between NKU and Rockwell Automation was reached. Under this agreement Rockwell provided state of the art automation and control equipment at subsidized cost and NKU agreed to provide the laboratory space, infrastructure support as well as the complementary funds for hardware and software renewal fees. The Rockwell offer have included equipment for 10 workstations, as per Table 1:

**Table 1 - List of equipment for the mechatronics laboratory**

Item	Description	Qty.	Notes
1	Allen-Bradley 5580 controller w/ power supply, 7 slot chassis and analogic input & output modules	1	Supplied by Rockwell
2	Human Machine Interface (HMI) w/ power supply	1	Supplied by Rockwell
3	Variable frequency Drive	1	Supplied by Rockwell
4	PC desktop computer	1	Supplied by NKU
5	Ethernet switch	1	Supplied by NKU

A homemade commonly used input/output device box/panel is being developed by students under faculty supervision, funded by an internal research grant. A mini- conveyor belt, photoelectric and color sensors and motors are also included to closely simulate real industrial control systems. The integration with existing Fanuc robots is also envisioned.

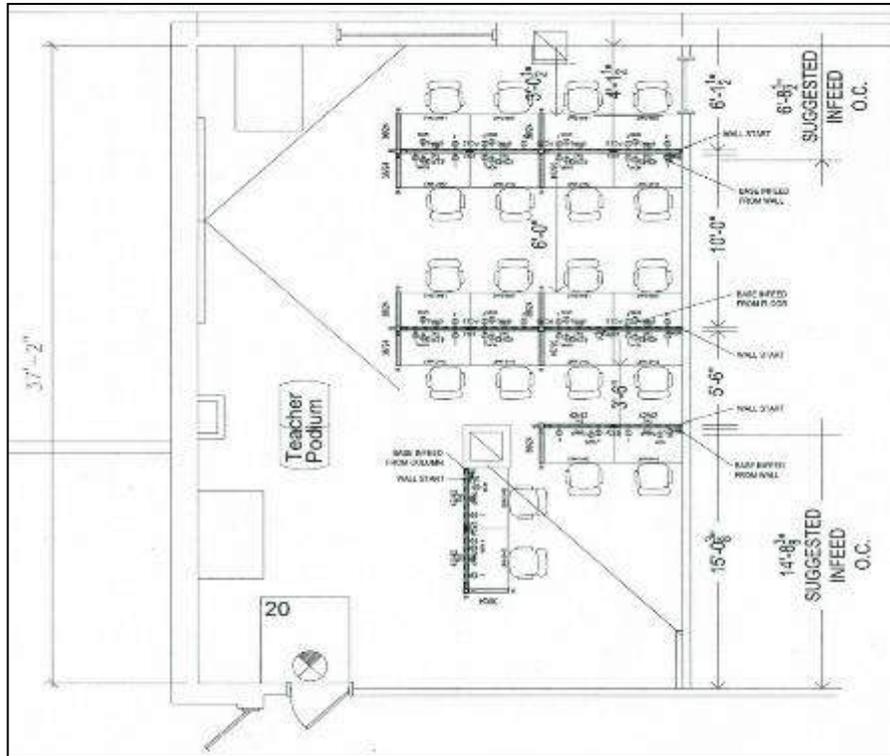
It is expected that this lab will:

- Support laboratory-based experiential learning in state-of-the-art Allen-Bradley PLCs, ladder diagram PLC programing within Studio 5000 environment, instrumentation and control systems design, etc.
- Provide a real industrial automation environment for EGT students to assemble, program, and operate integrated manufacturing systems.
- Give capstone design students the opportunity to facilitate their design of systems, development, and testing to meet the needs of project sponsors.
- Allow the EGT faculty top conduct all sorts of applied research in manufacturing, intelligent product design, networks, and mechatronics engineering.

Moreover, the lab can be used to support K-12 STEM education and recruit more students from the area community and technical colleges in an effort to create awareness of STEM disciplines in general and in engineering in particular.

After a procurement for a suitable space, the campus planners decided to proceed with the installation in an existing classroom located in the BC building, as indicated in

Figure 5. This decision was based on the resources needed for renovation and network/electrical connections availability. The layout for the laboratory is depicted in Figure 7 below:



**Figure 7 - Mechatronics laboratory layout - room BC106**

Figure 8 depicts the mechatronics laboratory at an advanced stage of completion.



**Figure 8 - Mechatronics laboratory - general view**

Existing furniture sourced from an existing computer lab was retrofitted with slot panels to accommodate the equipment, which was inspired in the PLC laboratory implemented at Kent State University under a similar UIC initiative. This arrangement allows flexibility for future expansion or upgrades in the workstations.

## 7. CONCLUSION

The Mechatronics lab is designed to meet the needs of industries employing engineering graduates in Northern Kentucky, Southern Ohio and Southeast Indiana areas; skilled mechatronics engineers and technologists are in demand to support their integrated manufacturing industry needs. This facility is equipped to prepare students to fill positions in automation, control, instrumentation design, and robotics areas.

A dedicated mechatronics laboratory is necessary, not only to support the new Mechatronics program, but also to improve the classes from the other programs that will become part of the curriculum; the design of laboratories like this one is also important.

Other mechatronics programs may find aspects of the NKU design of educational spaces and framework useful. Moreover, collaboration with the private sector expands and enhances the academic experience of students. The embedded workforce development opportunities are advantageous to the students, institutions, and employers in ways far beyond what was articulated here.

## 8. FUNDING

This paper was prepared and presented thanks to the financial support received from Northern Kentucky University College of Arts and Sciences Professional Development Award.

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## Sustainable Redevelopment in Fitchburg: A Collaborative Faculty-Students-Community Engaged Project

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**Abstract:** Collaborative faculty-students-community engaged (FSCE) projects with strong pedagogical and innovative service-learning approaches can dramatically transform and expand higher education and curriculum outcomes. FSCE projects provide a platform for concerned stakeholders to share knowledge and learning opportunities by integrating community serving, which in many cases improves the quality and productivity of instruction. These projects focus on issues and can ultimately contribute to the well-being of the community. This paper focuses on a pilot study of the City of Fitchburg in Massachusetts, a 19<sup>th</sup> century industrial center that has now, like many other New England early mill towns, lost manufacturing and its base economy to other states and countries with lower labor costs. The infrastructure built over the last two centuries has stayed the same or is deteriorating and now needs to be repurposed and given a thoughtful upgrade. There are many critical factors that can be analyzed and addressed to make this city a better community to live, study, and work in. By conducting a pilot study, this paper identifies major issues and analyzes existing scenario of community connectivity involving concerned local stakeholders. The authors propose a research framework to conduct a FSCE project by collaborating with concerned stakeholders and community design experts. This paper presents three case studies where Fitchburg State University's faculty and undergraduate students were actively involved in the redesign of various city related projects that represent the significance of this type of collaborative and integrative faculty-students-community engaged project for enhancing community-engaged learning opportunities for undergraduate students.

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### 1. INTRODUCTION

There has been a dramatic transformation of higher education and curriculum outcomes after the expansion of partnerships among universities, communities, and other organizations (Driscoll et al., 1996). Partnerships such as these not only connect faculty and students with communities and organizations but also provide a common platform for concerned stakeholders to: (i) share knowledge, (ii) learn by serving communities, (iii) integrate community serve-learning models into the academic curriculum, and (iv) provide an innovative pedagogical approach to realizing higher education's civic responsibilities. These partnerships ultimately improve the quality and productivity of instruction as well as address community problems (Bringle, Games, & Malloy, 1999; Bringle, Hatcher, & Games, 1997; Driscoll et al., 1996; Edgerton, 1995; Nicotera et al., 2011). Service-learning partnerships may fail though and not achieve their desired outcomes because of a lack of collaboration among team members, minimal institutional commitment, lack of administrative support, lack of faculty participation, and lack of funding (Morton & Troppe, 1996; Ward, 1996). Of these factors, faculty participation is the most critical (Ward, 1998) because implementing service-learning into a curriculum is based upon faculty commitment (Bringle & Hatcher, 1995). Studies show that there are various factors that motivate faculty participation in service-learning, such as, student course-based learning, relevance to course materials, self-direction, improved student satisfaction with education, personal involvement in service and enjoyment of working with students in co-

curricular settings, other student co-curricular factors, institutional recognition of service-learning as a scholarly activity, encouragement and faculty support by their administration and colleagues (president or chief academic officers, college deans, department chairpersons, and other faculty members), teaching strategy, institutional support for service-learning, the type of institutions, and academic discipline (Abes, Jackson, & Jones, 2002; Gray et al., 1999; Hammond, 1994).

Considering the benefits of a service-learning pedagogical approach, several universities have incorporated Faculty-Students-Community Engaged (FSCE) projects in their curriculum through various courses (especially senior design or capstone courses). For example, Driscoll et al. (1996) presented an assessment model for service-learning through comprehensive case studies of their impact on the faculty, students, community, and institution. Ma et al. (2016) also conducted research on service-learning's impact on faculty and developed a faculty engagement model.

This paper presents a framework to conduct a Faculty-Students-Community Engaged (FSCE) project. A FSCE project provides a common platform for all stakeholders (such as faculty, students, community representatives, local industry, professional organizations, and city officials) to identify existing issues in a community or city. FSCE projects also create dual opportunities for students in both learning and community service. This paper explains various stages in the research framework. This research not only contributes to the body of knowledge but also develops a foundation for designing a systematic strategy for the effective implementation of a FSCE project. In addition, this paper presents a pilot study that determined major issues in the Fitchburg community and three case studies on how Fitchburg State faculty and students contributed to the welfare of the city. Moreover, this paper explores and presents how to integrate learning outcomes from these projects into a program's curriculum.

## 2. BACKGROUND

Fitchburg, settled in 1730, is one of the older cities in Massachusetts. Officially, it was set apart from the Town of Lunenburg and incorporated in 1764. The city was named after John Fitch, one of the committee member that procured the act of incorporation. Fitchburg is known for heroism (Fitchburg History, 2020). This city is located in the northern sector of Worcester County and has an area of about 28 sq. mile. Based on population, it is ranked 37 out of 348 towns and cities in Massachusetts. Fitchburg was connected to Boston via railroad in 1845. By 1872, Fitchburg became a city with many primary institutions, such as a courthouse, hospital, library, opera house, and municipal buildings located in or near the downtown. It became an industrial center during 19<sup>th</sup> century through the use of water power, then coal and steam to operate its mills and factories. These factories produced machines, tools, clothing, paper, saws, chains, axle, grease, bicycles, shoes, and firearms. This city was later linked by rail to western markets with the completion of the Hoosac railroad tunnel in North Adams. Fitchburg is noted for its Victorian style architecture that flourished during this industrial expansion. The city has had a diverse population including Irish, Italians, Finnish, Greek, English, and French Canadians and more recently has added a sizable Latino and Hispanic population.

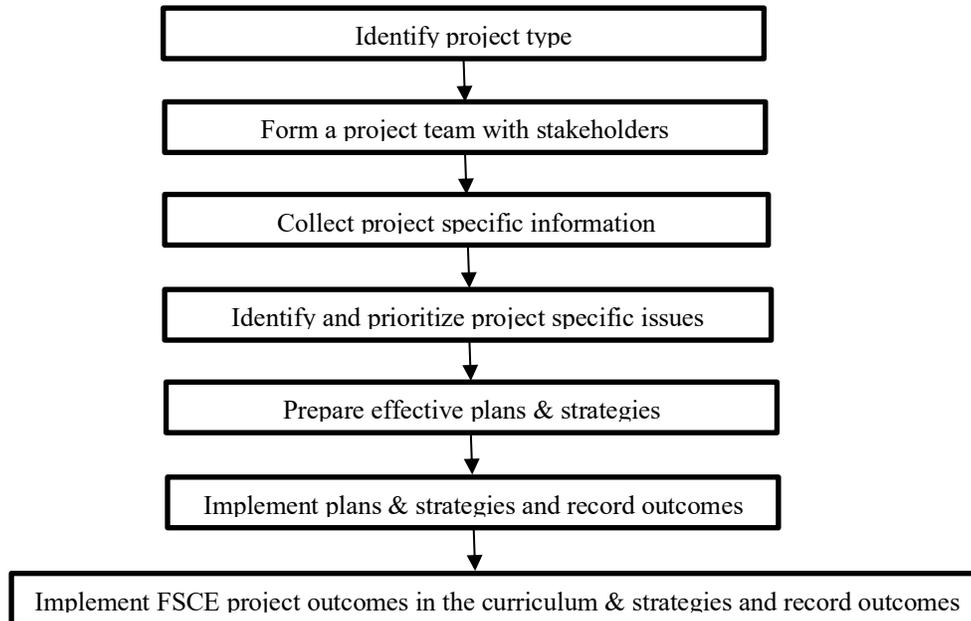
Fitchburg's golden years began to fade in the early 1900's. The upper middle class family began to move out to the suburban and neighborhood began to lose their economic diversity and stability. Local industries began to change ownership and move away. The business enterprise (shops, theaters, hotels, factories, and banks) slowly declined. Fitchburg, the industrial center of Massachusetts in 19<sup>th</sup> century, slowly collapsed during the 20<sup>th</sup> century (Fitchburg History, 2020). Currently, more than 18% of the city's population is below the poverty line. Because of the decline, most city buildings and infrastructure are aging and need effective strategies and planning to bring them back to their vibrancy of the past.

Fitchburg State University is a public comprehensive institution of higher education and has offered degrees since 1897. As an anchor institution within the city and the region, the university is now a prime employer and partner in the regional economic development and has initiated a collaborative outreach to Fitchburg and other surrounding communities. In the northeast, Fitchburg State ranks 51<sup>st</sup> in the U.S. News Ranking and World Report and 1<sup>st</sup> in the Commonwealth of Massachusetts among the regional comprehensive universities for social mobility (Fitchburg State University, 2019). Fitchburg State is

contributing to regional development with a designated strategy to: (i) produce a highly skilled and motivated workforce, (ii) expand and diversify the regional economy with job growth, & (iii) strengthen and expand the region’s small business base.

### 3. RESEARCH FRAMEWORK

Based upon literature reviews and past working experiences in similar community engaged projects, the authors have developed a research framework to conduct Faculty-Students-Community Engaged (FSCE) projects as shown in Figure 1. This is a generalized framework which can be updated based upon project requirements.



**Figure 1. Research framework**

As this paper is focused on determining major issues in Fitchburg and is directed toward the sustainable redevelopment of the city. The concerned stakeholders for this project are faculty, students, community representatives, and city officials. These form a project team inviting other faculty and industry experts as they are required. Project specific information is collected by adopting suitable methods, such as focus groups, survey questionnaires, interviews (Driscoll et al., 1996), and collection of feedback during community meetings and workshops. City/community specific issues are identified and prioritized by analyzing the data and conducting broad discussions among the concerned stakeholders. Through extensive discussion, investigation and design, effective plans and strategies are then prepared for implementation toward sustainable redevelopment in the city. The collected information, detailed plans, strategies, and outcomes from the project are recorded and shared among all concerned parties for review and adaptation. Upon completion or during the working process, achieved learning outcomes are further integrated and adopted into the relevant course curriculum for future students.

### 4. PILOT STUDY

A pilot study was conducted to identify the major issues in the Fitchburg community. A preliminary questionnaire survey sheet was designed that consisted of eight sections: quality of life, community characteristics, business and population growth, code enforcement, community safety, personal safety, service quality, and government service overall. For this preliminary study, the focus group consisted of Fitchburg State students who reside in Fitchburg and their relatives and friends who live in Fitchburg.

According to the survey report, most participants mentioned these issues:

- Unemployment and poverty, and noted that many people with jobs need to travel Boston and Worcester
- City infrastructure, such as roads, buildings, and bridges are aging and need regular maintenance. Bridges and structures should be monitored and tested for structural stability.
- Downtown is mostly empty and needs a strategy for new business and reuse.
- Public safety and reduction of crime
- Senior citizen and others demand more frequent public transportation

The university and city have coordinated to address some safety issues by installing surveillance systems to monitor possible criminal activities. The university is also renovating a downtown theater building incorporating some university course classrooms, meeting rooms, and an Idea Lab helping to bring some activities back to downtown.

## 5. RESULTS & DISCUSSION

The preliminary study indicated that unemployment, aging infrastructures, public transportation, and safety are the primary issues for Fitchburg. This paper presents three case studies related to aging infrastructures issues, typically building and area development projects. All of these projects were Faculty-Students-Community Engaged (FSCE) projects, and are briefly explained in the following section.

### 5.1 Case 1: Fitchburg City Hall Area Development

The two-story Fitchburg City Hall, built in 1853, has Italianate design features a granite foundation, brick walls and pilasters, brownstone and terra cotta details, granite lintels, and a slate roof. The building had offices on the first floor and a large public meeting room with a balcony on the second floor that was later transformed into additional city office space. The 166-year-old City Hall was declared unsafe for habitation in 2012 after a broken roof truss was found (Semon, 2019). As this building is a symbol of pride, resilience, and strength in Fitchburg, Prof. Keith Chenot found this issue as an opportunity for architecture students to develop their knowledge and skills by seeing and understanding real property conditions, experiencing a lack of commercial and residential density in this urban space, and its potential for redevelopment. A total of eleven Architectural Design I students were involved in the “Fitchburg City Hall Area Development” project. The project team not only restored and redesigned City Hall but also expanded the redevelop plan to nearby underused buildings and vacant properties adjacent to the river (shown in Figure 2). The students presented their project to the mayor, other city officials, the Historical Commission, invited citizens, and the press. City Hall is currently under reconstruction and is expected to be complete by fall 2020.

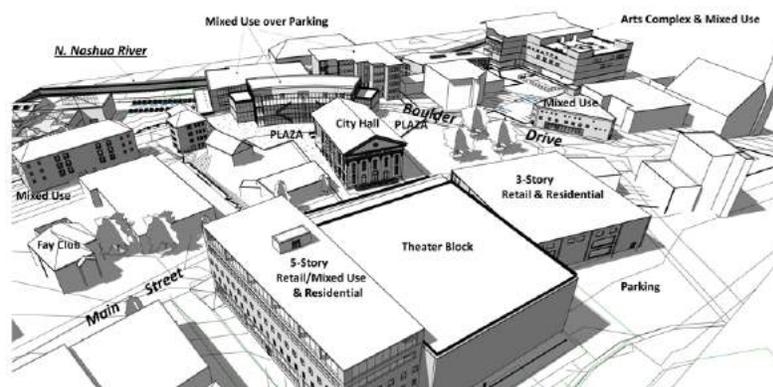


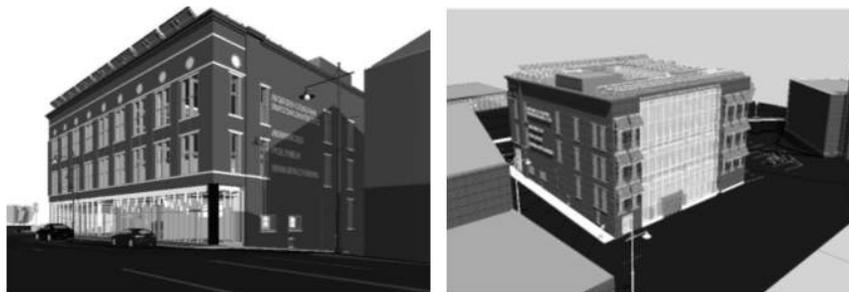
Figure 2a. Fitchburg city hall area development (courtesy: D. Keith Chenot)



**Figure 2b. Fitchburg city hall area development (courtesy: D. Keith Chenot)**

## **5.2 Case 2: Feasibility Study on an Advanced Polymer Manufacturing Research, Technology Transfer and Training Facility**

North Central Massachusetts, especially Fitchburg, Leominster, and Gardner had been recognized as a hub for manufacturing industries (mainly the plastics industry) for a long time (Worcester Business Journal, 2012). Backed by the local Chamber of Commerce, manufacturers expressed their need to experiment with new methods and technologies to improve productivity and profitability, but they lacked the facilities and expertise for research, experimentation, and workforce training. Other studies have shown that local manufacturers need workforce training and education program, training facilities, and technological advancement to sustain their industry (University of Massachusetts, 2000). Considering this reality, Prof. Keith Chenot and eight student interns conducted a feasibility study and analyzed the potential for an advanced polymers research, technology transfer and training center in an unused commercial building on lower Main Street in Fitchburg (shown in Figure 3). The student team coordinated with Regional Economic Development Institute (REDI) project Director (Dr. Joshua Spiro), the North Central Massachusetts Development Corporation, and the North Central Massachusetts Chamber of Commerce. The team redesigned the existing four-story commercial building and added energy saving features, such as daylighting with solar control, a south facing energy wall, PV solar rooftop arrays, and a geothermal ground-sourced HVAC system. The new design consisted of business incubator offices, shared conference rooms and classrooms, administrative offices, and experimental manufacturing laboratories (such as nano-polymer lab, cleanroom labs, machine shops).



**Figure 3. Advanced polymer manufacturing research, technology transfer and training facility  
10 Main Street, Fitchburg, MA (courtesy: D. Keith Chenot)**

### 5.3 Case 3: An Amazing Plan for Moran Square, Fitchburg MA

In collaboration with the Fitchburg Redevelopment Authority & Consultant Jerry Beck, Prof. Keith Chenot and his eight Architectural Technology students coordinated a revitalization plan for Moran Square, the eastern terminus of Main Street in Fitchburg and also near the university. This redesign incorporated a mix of residential and small business spaces that would provide a synergy that builds and supports a vibrant community and also provides employment for residents and university students. They also studied the open space between a plumbing supply building and the MART intermodal terminal to enhance an existing park by creating a small memorial park that would feature the re-sited Spanish-American War monument, a new space to honor Gulf War veterans, and additional open landscaped areas. Their scheme converted existing open parking to a public park featuring water features and skating in the winter. In addition, they studied streetscape improvements supporting pedestrian areas and crosswalks, and developed creative nighttime lighting to feature the historic buildings in the area and heighten the excitement of Moran Square (as shown in Figure 4).



**Figure 4. Proposed plan for Moran Square, Fitchburg, MA (courtesy: D. Keith Chenot)**

## 6. CONCLUSIONS

This paper presents a research framework to conduct a collaborative Faculty-Students-Community Engaged (FSCE) projects, which is an innovative pedagogically rich service-learning approach to education. FSCE project provides a common platform for all concerned stakeholders to share ideas and knowledge to research and resolve existing community issues. It also creates dual opportunities – learning and community service opportunities – for students involved in the project. The authors conducted a pilot study to determine the major issues in Fitchburg by conducting survey questionnaires among a focus group. The three case studies by Fitchburg State faculty and students show how these projects can contribute to the welfare of a community. These projects can also be an aid to urban planners and local authorities in planning and executing effective strategies toward positive and sustainable redevelopment in their community. Through the use of this type of project, students gain insight into their ownership and responsibilities citizens in their community. In addition, this paper explores and reports how to integrate the learning outcomes from these projects into the future curriculum. This type of project can be a foundation and a common learning platform for students who want to be involved in real-world projects for their senior level projects, such as a capstone course. It is necessary to identify suitable courses that can incorporate the outcomes from a project, based upon the characteristics of project and individual course objectives. Lastly, service-learning partnerships in the FSCE projects highly depend on true collaboration among their team members and having robust institutional commitment, faculty participation, administrative support, and proper funding.

## 7. ACKNOWLEDGEMENTS

Authors acknowledge the assistance of all undergraduate students who were actively involved in Fitchburg related projects and express their special gratitude to the city officials, community representatives, and organizations involved with these projects. Without their support, these case studies would not have been possible.

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## Engaging Upper Elementary Students In Activities Aimed To Increase Female Inclusion In STEM

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**Abstract:** This paper discusses efforts by the Center for the Advancement of Women in Engineering (CAWE) at the University of North Florida (UNF) to increase the inclusion in STEM by engaging 3rd through 5th grade students in outreach activities in the form of field trips. The UNF-CAWE field trips are designed to educate and inspire students in 3rd through 5th grade about engineering using a hands-on approach. The learning materials were designed to be inclusive to a diverse population. The materials included a conversational presentation of what engineering is and how it has helped shape the world we live in today and how engineering is needed to solve some of the biggest challenges our society is facing. The presentation was followed by engineering activities during which the students learned basics of programming a robot and building a hydraulic system capable of lifting heavy weights. The presentation and activities were designed by engineering students and faculty in the engineering and psychology programs and were delivered by engineering, computing, and psychology students with the oversight of the directors of CAWE. A total of six field trips were conducted. Three of the field trips received an additional presentation on unconscious gender biases. For all the six field trips, children with parental consent, participated in an Institutional Review Board (IRB) approved research study to determine if their interest in pursuing a STEM career was affected by the unconscious gender bias discussion. Results from the pilot study reveal that children benefit from participating in outreach activities which provide exposure to engineering, hands-on activities, role models, discussions on how engineering makes the world better, and discussions of unconscious gender biases.

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### 1. INTRODUCTION

Women are underrepresented in engineering and some other STEM fields in the United States with only 12% of engineering jobs filled by women [1]. The need to increase women's participation in the field stems from the need for diversity of thought and from the need to meet the growing demand for engineers. The number of women earning engineering degrees has slowly increased in the last 30 years from approximately 15% in 1985 [1] to about 20% in 2015 [2]. In Computing, the number of women earning computing degrees has declined from 37% in 1985 to 18% in 2013 [1]. This low number of female graduates in engineering and computing is in stark contrast to the percentage of bachelor's degrees earned by women, which has been steady at approximately 57% since late 1990s [3]. Women do not pursue engineering at the same rate as men in part because of unconscious gender biases [4, 5], and lack of female role models [6]. These biases lead girls and women to question their abilities and feelings of belonging. The unconscious biases start at an early age and already at the age of seven, it has been observed that mathematical ability is associated more strongly with boys than girls [7]. These unconscious gender biases are believed to originate from children's interactions with parents, teachers, and media [8]. In a longitudinal study [9], it was found that

teachers perceive boys to be stronger in math than girls and that the performance gap in math between the genders increases through elementary school and that these differences are related to the teacher's perception of math abilities. Additionally, children are exposed to unconscious biases from parents and media. These unconscious biases lead girls to question their abilities and if their gender identity agrees with that of engineering. It is known that when gender identity conflicts with other social identities, self-stereotyping and reduced confidence can result [10, 11], and this may be a contributing factor as to why girls and women steer away from engineering and other STEM disciplines [12, 13], and may even contribute to lower performance. The Center for the Advancement of Women in Engineering was created to help bring gender equality to engineering and other STEM fields.

## **2. THE CENTER FOR THE ADVANCEMENT OF WOMEN IN ENGINEERING**

The Center for the Advancement of Women in Engineering at the University of North Florida is committed to increasing women's participation in engineering through recruitment, retention, and advancement strategies based on research knowledge. By increasing inclusion of women and other minorities, our profession is better able to meet the growing demand for more engineers and increase diversity of thought, needed in determining the most important problems to solve and in developing the best solutions. CAWE provides a variety of outreach activities for children in K-12 with the aim to inspire them to consider engineering and other STEM fields as a career. For retention of female students in college, CAWE provides a variety of mentoring opportunities with industry members, faculty, and peers. CAWE is also vested in the advancement opportunities for women in the community and actively engage with them in networking opportunities to share success strategies in how to recruit and retain women.

## **3. RESEARCH STUDY TO INVESTIGATE IMPACT OF UNCONSCIOUS GENDER BIAS DISCUSSION**

To increase the inclusion in STEM, the PIs performed a pilot study by augmenting an existing outreach program called *Introduce a Girl to Engineering Day* by introducing a research component. The pilot study was conducted on 97 girls aged 8 to 12 and 95 parents across two years. While boys were invited to the event, only one attended and did not participate in the study. The research investigated the children's previous exposure and knowledge of STEM and their interest to pursue engineering. An on-line survey in the morning of the event, at the end of the event, and then again three to six months following the event was conducted. The event included, in addition to hands-on engineering activities, a presentation in which gender stereotypes were discussed. The preliminary results led to expanding the pilot study to investigate the effect of inclusion of gender discussions in STEM activities in boys and girls. This expanded research study was conducted on 3<sup>rd</sup> to 5<sup>th</sup> grade children attending six separate school field trips at the University of North Florida, with participants from four schools. All field trips were equivalent, except three included a gender discussion, whereas three did not. These field trips included approximately 50% girls and 50% boys.

### **3.1. Pilot study: Introduce a Girl to Engineering Day (IGED)**

The pilot study was carried out on the IGED program offered in two separate years. In both years of the program children were brought to the University campus on a Saturday by their parents or caregivers. The event was broadly advertised on social media, TV, and radio. The day included children completing a pre-program survey, attending a presentation on engineering and a brief discussion of gender biases, and engaging in hands-on engineering projects that related to societal needs. After completion of the projects, the children were asked to take a post-program survey. Parents were also surveyed prior to the program. Three to six months following the event, the children were given a follow-up survey conducted on-line at their home. The surveys were designed to ascertain the children's prior exposure to and understanding of engineering and STEM and to determine whether participation in the program increased their interest in

pursuing engineering. The average results and standard deviation of the pilot study are provided in Table 1. In the table, engineering understanding and aspirations are measured on a 5.0 scale.

**Table 1: Results of pilot study**

	Pre-survey	Post-Survey	3- to 6-month follow-up
Number of participants	94	97	65
Engineering understanding	3.63 (0.88)	4.46 (0.58)	3.75 (1.15)
Engineering aspirations	3.51 (0.96)	3.68 (0.99)	3.28 (1.36)

These preliminary results of the pilot study indicated that a one-day engineering outreach program with gender unconscious bias discussion, hands-on activities connected to how engineering can improve society, and female role models, increases the girls’ interest in pursuing engineering following the activity and their knowledge of engineering. The follow-up survey indicates that a one-time exposure may not be enough. The follow-up study was conducted at home, whereas the pre- and post- study was conducted at the event, which may have an impact on the results. Further, it is known that girls’ interest in STEM decreases with age and the follow-up survey does not consider that participants moved to a new grade level and in some cases from elementary school to middle school between the event date and the follow-up survey. The pilot study was conducted on girls only and hence no comparison could be made between genders.

**3.2. Expanded study: Girls and Boys can do Engineering! field-trip program**

The purpose of the expanded study was to recruit a diverse sample of both boys and girls and to examine whether discussion of gender bias contributes to changes in children’s interest in engineering. Children were recruited to participate in this research study as part of a field trip program developed by CAWE. The opportunity was advertised by the Duval County Public School (DCPS) district to school principals. The participants included 69 girls (2nd grade: 2, 3rd grade: 4, 4th grade: 14, 5th grade: 49) and 64 boys (2nd grade: 2, 3rd grade: 7, 4th grade: 15, 5th grade: 44). The children completed a survey prior to the start of the program, then again at the end of the day in the same computer lab, and will complete a follow-up questionnaire three to six months post the program at home. One parent per child has also been asked to complete a similar parent survey. As an incentive for research completion, the children are offered a small gift card. Children were not required to participate in the study in order to partake in the field trip. The research study was approved through a university based Institutional Review Board (IRB) and through a DCPS based IRB.

The program was designed and led by professors in psychology and engineering. Five female students in engineering/computing and five female students in psychology provided the activities on the days of the field trips, with oversight from the professors and an outreach coordinator. The team consisted of women with varied racial and ethnical backgrounds, providing representation of otherwise under-represented groups, and showing that women can be successful in STEM fields.

Questions were asked to assess the child’s past exposure to engineering and STEM through previous activities such as reading, games, toys, watching TV shows, and if the child knew an engineer. The children were also asked questions to assess their unconscious gender biases, including their perception of their own and others’ strengths. The children and parents were asked to rate the child’s interest/likelihood of pursuing a STEM career. The children’s surveys were designed to be easy for the children to complete, as demonstrated with the sample questions shown in Figure 1.

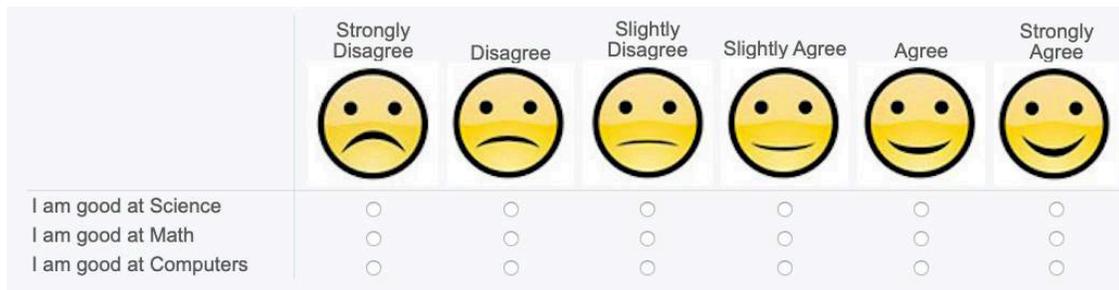


Figure 1: Sample survey questions

#### 4. ACTIVITIES AIMED TO INCREASE INCLUSION IN STEM

After the initial survey, the children were brought back into a classroom designed for engaging children in STEM activities where an engineering student gave an interactive presentation discussing what engineering is. All children attending the field trip attended this presentation as a large group together, with an average of 24 children in attendance for any of the field trips. After an initial explanation of what engineering is, the children drew a picture of their impression of an engineer, and then watched a short video of engineering designed for their age group. At that point, three of the schools attending the field trips were engaged in a discussion on unconscious gender biases and three of the schools continued the presentation without the discussion of gender. The gender component is described in section 4.1. The focus of the engineering talk was to showcase how engineering helps make the world better, how engineering touches all aspects of our lives, and how engineers are problem solvers. A variety of examples were presented, ranging from designing windmills, safer roads, communication devices, prosthetics, biomaterials, and how engineers aid in improving the air and water quality. It was also pointed out the breadth of engineering and the different ways in which someone can contribute in this field. For example, it was shared that engineers can be creative, have a desire to design, have a passion for tinkering and building parts, enjoy solving problems, and be good at math, and that people with different strengths are needed in engineering. Following the discussion of engineering, the students engaged in two hands-on engineering activities; one on robotics, and one on hydraulics.

##### 4.1. Gender Discussion

Half of the groups attending the field trips participated in a slightly longer presentation, which included an unconscious gender bias discussion. Half of the groups did not receive this component and serve as a control group. The purpose of the unconscious bias component was to help make the children aware that women are underrepresented in engineering and some other STEM fields and that they are equally capable to be successful in such fields. The children were informed that only about 12-14% of engineers are women. They were shown a graph indicating that IQ scores and school grades of girls and boys are equivalent. Discussion of gender stereotypes followed, where the children provided their thoughts on stereotypes and the presenter shared how some of those stereotypes may be created. For example, the children were shown images of two magazine covers; one directed at boys and another directed at girls. The messages of the magazines were distinctively different; the boy's magazine was about exploring his future, whereas the girl's magazine was about fashion and looks. The discussion also emphasized the importance of having a diverse group of engineers. One example that illustrated this importance included findings that women are more likely to be injured in car accidents than men, potentially because not as many women have been engaged in the design and safety testing of cars. The gender discussion concluded with ways to engage girls more in engineering and other STEM fields and that the children should think critically about the gender-related messages they encounter so that they can be open minded about career and life decisions.

## 4.2. Engineering Projects

After the presentation on engineering (and gender discussion for half of the groups), the children were split into two classrooms, and further subdivided into groups of approximately 3-4 children. Teachers were asked prior to the field trips to subdivide their children into groups and to ensure, to the extent possible, that there was gender balance within the groups. Half of the children started with a robotics activity before a lunch break and continued with a hydraulics activity after the lunch break. The other half of the students completed the activities in the opposite order.

### 4.2.1. Robotics activity:

A computing student gave a short presentation related to coding and robotics and presented how these benefits society and gave an example of how computer scientists are involved with controlling autonomous cars. She then presented the hands-on projects the children would work on. This project was meant to help the children understand how coding can be used to help solve societal problems. They were given a scenario that a hurricane in 2040 would cause much of the sand on the beach of Jacksonville, FL to erode and that the City of Jacksonville was asking that they deliver sand from a stockpile located in northwest Jacksonville to the damaged north section of the beach. The children were given a robot, and a wood frame with the details such as the city beach, the stockpile of sand, and the parking lot for their vehicle. The children were provided detailed descriptions on how to program their robots using the mBlock Blockly App. The instructions included images of the user interface and examples of block codes available to them, as seen in Figure 2.

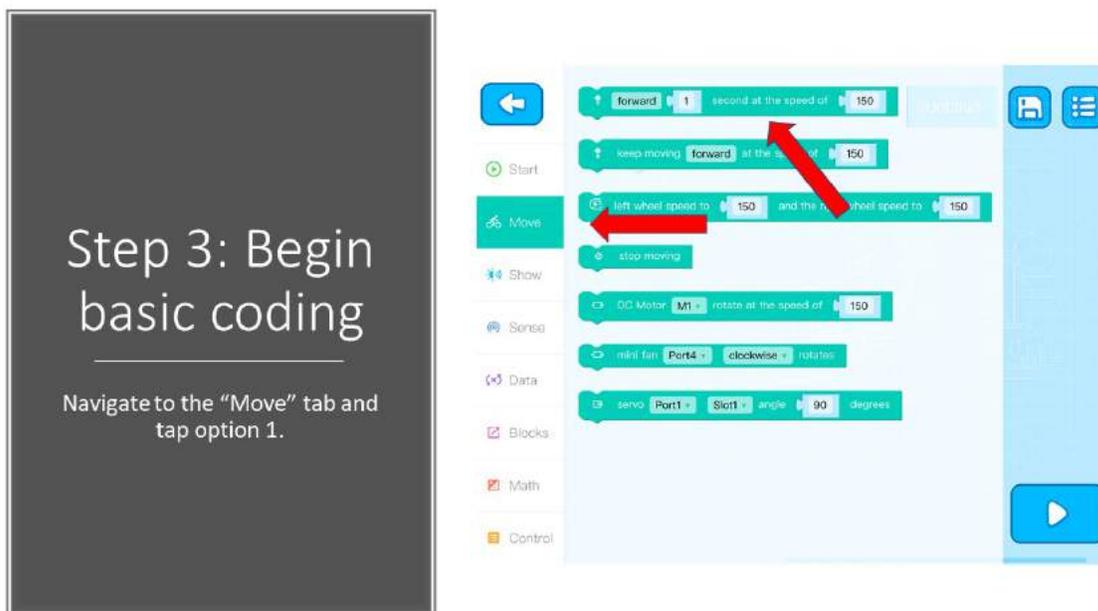


Figure 2: Coding instructions

The children worked in their small groups of approximately 4 children. They wrote code, and then tested it on the wood frame, and repeated the process until they managed to solve the coding exercise. Figure 3 show the children working on this project.



**Figure 3: Participants testing their robot on the wood frame**

The children demonstrated an ability to learn coding and apply it to solve the problem posted to them. Also, the children were excited to engage in this activity and didn't want to stop when asked to.

**4.2.2. Hydraulics activity:**

The students also engaged in an activity on hydraulics. First, one of the college students gave a presentation on what hydraulics is and how it is used in applications in our society. Examples such as lifting a car and lifting patients in hospital beds were presented. The children were then asked to build their own hydraulic system that would allow them to lift a heavy weight using only small syringes pushed closed by their hands. The children were provided step-by-step instructions with detailed images on how to build the system and were provided the necessary syringes, tubes, connectors, and wood boards. The final system is shown in Figure 4.



**Figure 4: Hydraulics system**

The students learned about hydraulics, building, following instructions, and to problem-solve, especially when the system leaked water. In the end, they were happy to see their systems work and impressed that they could lift a person with the push of a few small syringes, as seen in Figure 5.



**Figure 5: Children lifting of person with the push of small syringes**

## 5. CONCLUSION

Women are significantly underrepresented in Engineering and many other STEM fields. The objective of this paper is to highlight one approach to increasing the number of women in these fields. Previous research has indicated that the lack of representation of women in STEM may, in part, be related to gender biases that become apparent and exert influence beginning in childhood. The approach summarized in this paper includes outreach activities for children that include the evaluation of gender biases and engineering activities designed to provide children with hands-on experience and access to relatable role models. Preliminary results demonstrate positive trends following exposure and that more than one-time exposure may be needed for lasting effects. These types of interventions may be critical to improving the number of women pursuing engineering and other STEM fields.

## 6. ACKNOWLEDGEMENT

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## A Usability Study of Airline Booking Platforms

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**Abstract:** The purpose of this study was to assess and compare the usability of booking airline flights on an airline’s mobile app and on the same airline’s website. The method of this study was a usability test where participants gave detailed evaluations of their thoughts while using two platforms. This study was conducted using a laptop and a smartphone. The five participants were assigned to either a group where they had to book a flight on the PC first or the mobile application first. They were timed while they completed a series of tasks such as finding a specific flight, adding a first-class upgrade, and adding a service animal. The test showed that users took approximately half as long to complete the booking process on the mobile application when compared to the website. Most of the users, however, felt the website was a more user-friendly interface despite it taking nearly twice as long to complete. The users explained that they felt the website had more information to aid in making booking decisions as well as more defined buttons, so it was less difficult to make a mistake. This feedback was unexpected since all of the participants were members of Generation Z. This result is important because it could be used to help airlines redesign their mobile apps to give more information about flight options. It also hopefully could inform airlines that even though Generation Z grew up with smartphones and mobile technology, they still prefer the website for booking flights.

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### 1. INTRODUCTION

In years past, if a traveler wanted to purchase an airline ticket, he/she would have to either go through a travel agent, call the airline booking office, or go to the airport in-person to complete the purchase. With the advent of the internet in the mid-1990s, travelers can purchase their tickets online from the comfort of their own home without the complicated extra steps. Airline reservation systems are now so automated that they can digitally generate boarding passes that can either be printed or loaded on a mobile phone. In the late 2000s, smartphones started to become commonplace, and airlines started using mobile apps for booking, checking in, and monitoring flight status. Most airline mobile apps also allow for checking of frequent flyer program points and status.

The reason why airlines spend money developing and updating their mobile apps is that travelers want to be able to check their flight status conveniently and on the go. Airline customers come from a diverse variety of backgrounds, so users demand a simple interface that is understandable by everyone. For example, a major airline based in the United States could fly to over one hundred different countries that all speak different languages. It must be easy for a user to figure out how to translate the website/mobile app into his/her native language.

Airlines need to know whether their public interfaces are as usable as possible. While the interface may seem straightforward to the designers of the system, ultimately the judge of usability is the end-user. Most people have booked an airline ticket, but what if the customer needs special services? Is it still easy to find the information the customer needs? If so, there is a genuinely usable interface. If not, more work can be done. The purpose of this study is to assess the usability of the website and mobile app of a major airline based in the United States.

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## 2. BACKGROUND RESEARCH

### 2.1 Website Usability Factors

A study by Lee and Kozar (2012) defines web usability as the effectiveness, expectancy, and satisfaction of a website. The Lee and Kozar article explain that the difficulty of measuring usability is that everyone defines usability in a different way. Another aspect of usability, according to the authors, is whether the website is slow. They explain that users will find a slow website less usable than a fast one, even if it is equally effective.

A paper by researchers from the University of Maryland explains how, in the modern world, having a web presence is necessary for companies that want to stay competitive (Agarwal & Venkatesh, 2002). The authors explain how corporate websites are used as places for public relations, financial transitions, finding out information, and more. Even more importantly, a website is typically the first impression of a company that a customer has. The Agarwal and Venkatesh study states that content, ease of use, promotion, and emotion are the most important factors in designing a website. Lee and Kozar (2012) also support this conclusion.

A study by Nathan and Lew (2011) highlights the point that perceived usability is subjective and differs from person to person. The authors describe how companies target their websites to audiences in age-based demographics. Nathan and Lew also explain how there are usability design guidelines for websites designed for children, teens, and the elderly. The Nathan and Lew study sought to establish usability design criteria for the college-aged demographic. The study evaluated 330 websites from various industries, including the airline industry, among a variety of usability factors. The study was measuring web usability factors that are similar to Microsoft Usability Guidelines. The guidelines are clarity of goals in the website, download speed, ease of web navigation, interactivity, trustworthiness, use of color and font, and use of multimedia. Clarity of goals refers to how clear the publisher makes their intentions. Download speed is how quickly the pages load. Download speed being a usability criterion is similar to Lee and Kozar's (2012) finding that users will find a slow website less usable. Ease of web navigation refers to how quickly a user can navigate around the website. Interactivity refers to how much feedback the user gets from his/her web interaction. Trustworthiness refers to how the user trusts the publisher and sponsor.

The researchers sampled approximately 400 students from a University in Malaysia. They were told to evaluate 40 different websites from the 36 different industries (Nathan and Lew, 2011). A vast majority of the responses came from female respondents. The study's results were divided up by industry. For the travel and transportation industry, the rankings of the web usability factors were (in order) trust of website, clear goals of the website, use of color and font, use of graphics and multimedia, ease of navigation, and interactivity (2011). This indicates that college-age users care the most about trust in the website and the sponsor's goals.

### 2.2 Application Usability Factors

A study by Baek and Yoo (2018) looked at the usability of branded mobile apps. They argue that this is important because 65% of all screen time is on a mobile phone. Branded apps are mobile apps that are branded for a particular corporation that one interacts with offline. The authors cite a Google study that claims that 36% of all apps go unused. They argue that this is alarming for businesses that spend millions developing apps only for them to go unused, especially when apps are a prominent form of interface with these corporations. Baek and Yoo wanted to find out what feelings users had while using apps that they liked.

Baek and Yoo (2018) asked 191 undergraduate college students 15 questions about the usability of an app that they liked. This would lead to the creation of a scale that could be used to assess the usability of the app. They determined that people cared about effectiveness, personalization (the feeling that one is a unique customer), fun, speed, and omnipresence. Omnipresence means it can be used at any place at any time. The Baek and Yoo scale assesses the perceptions the users have about the app as perceptions are

almost as important as facts. This is as opposed to other usability scales that only measure functional aspects.

A study by Cata and Martz (2015) takes an entirely different approach to app usability. It is looking at differences in perceived usability between designers and consumers. The authors explain how even though the designers may have good intentions and think that design is usable, it might not be to consumers. The authors explain that the amount of information users want in a mobile app can make designing an interface quite tricky. Users also do not want to have to spend a significant amount of time searching for specific pieces of information, which also increase the complexity. The Cata and Martz study found their designers and users all looked for similar things from their mobile app experiences. It also indicated that designers placed a higher emphasis on speed and aesthetics than regular users. This makes sense as designers tend to set higher expectations on the products they design.

### 3. METHODOLOGY

The airline website/app that was used was chosen due to the fact that the selected airline flies to a wide variety of countries where English is not the first language. After an airline was selected, usability test documentation was developed. The documentation consisted of an informed consent form, study instructions, a pre-survey, a task list, and a post-survey. Once the documentation was created, the documentation was submitted to the University’s IRB for exempt approval. Once the study was exempted from the full IRB process, participants were recruited. The participants were volunteers from the student body of a research university in the Southeast United States. The participants came from a variety of majors and backgrounds. This was an attempt to try to find a diverse sample. After the participants were read the informed consent form and agreed to participate in the study, they were presented with a pre-survey to complete. They were then given a list of six tasks to complete. The tasks were as follows:

**Table 1: List of Tasks**

Task Number	Task Description
Task 1 – on computer	Selecting a specific flight.
Task 2 - on computer	Determining whether an upgrade to first class is allowable for the given flight. The procedure specified that the participant could only upgrade to first class if it cost < \$1000.
Task 3 -on computer	Adding a service animal.
Task 4 – on the smartphone app	Selecting a specific flight
Task 5 – on the smartphone app	Determining whether an upgrade to first class is allowable for the given flight. The procedure specified that the participant could only upgrade to first class if it cost < \$1000.
Task 6 – on the smartphone app	Adding a service animal.

Note: Tasks 1-3 and 4-6 are identical. The difference between them is that one set is on the computer, and the other set is on the smartphone.

Three of the participants completed the tasks on the computer first, and two of the participants completed the tasks on the smartphone first. All of the participants used the same exact laptop and smartphone in an attempt to make sure technological differences did not contribute to the perceived difficulties in usability. The participants were timed in how long it took for them to complete the tasks, and their errors were written down on a log sheet. After all of the tasks are completed, the participants were given a post-survey, which consisted of questions regarding the platform’s use and their perceived usability.

#### 4. RESULTS

The study consisted of five participants. Two of the participants were female, and the remainder were male. All of the participants were between the ages of 20-25 years old, placing them in the Generation Z group.

**Table 2: Time Data (in Min:Sec)**

<b>Task #</b>	<b>Mean</b>	<b>Median</b>	<b>Mode</b>
Task 1	3:18	3:11	
Task 2	1:18	0:30	0:10
Task 3	0:20	0:18	
Task 4	1:49	1:31	
Task 5	0:29	0:29	
Task 6	0:16	0:15	0:15

With the exception of Task 2, all of the means were relatively close to the task median. In Task 2, there was one observation of 3:30 that pulled the task mean up. During one of the trials, the airline’s website froze and needed to be refreshed. As such, the task took slightly more time to complete.

**Table 3: Error Data**

<b>Task #</b>	<b>Mean</b>	<b>Median</b>	<b>Mode</b>
Task 1	0.8	1.0	1.0
Task 2	0.4	0.0	0.0
Task 3	0.2	0.0	0.0
Task 4	0.8	0.0	0.0
Task 5	0.2	0.0	0.0
Task 6	0.2	0.0	0.0

The average error between the two sets of tasks was relatively close together. For the purposes of this study, an error was defined as a mistake that the user could not quickly resolve on his/her own. Mistakes that were quickly resolved were not counted as errors in this study. Under this definition, most users made few to no errors. The tasks with the most errors were Task 1 and Task 4, which both required users to look up and select a flight on either the website or mobile app, respectively. These tasks, by far, had the most sub-steps.

All of the participants had little to no experience booking airline flights via a mobile phone app. Only one of the participants had significant experience using airline websites to book flights. The most common error on the mobile app was pressing the “find trip” button when trying to book instead of book flight. The most common error on the website was a participant not knowing how to select the flight he/she was interested in. Another common piece of feedback was that the website took too long to load and that the mobile app loaded much faster.

Users found the website to be much more cluttered than the app. One user commented about how she liked the streamed lined look of the mobile app and found it easier to use. All of the users commented about the “adding a service animal” task saying how if they had not been directed to add special assistance,

then they would have had trouble finding that section.

Users reported that the amount of information needed to be held in memory was minimal, as everything that needed to be remembered was put on the screen. Users found a high level of consistency between the two platforms

## 5. DISCUSSION

In terms of layout, users seemed to prefer the mobile app to the website. They found it more streamlined, faster, less cluttered, and easier to find trip information. The users overall preferred the less cluttered interface. This indicates that the user base wants to know exactly where to go and what to do without looking around at a lot of extraneous information. Many of the users reported frustration with the excessive load time of the airline's website. One commented that it did not make sense that the website loads slower since a website should have a better IT infrastructure behind it. A possible explanation for this is that the airline was focused on improving its mobile app experience that it ignored the main website experience. This would be the incorrect choice for the airline since all of the users studied had limited to no experience using the app to book flights. They all use the website for booking their flights. None of the users had ever used this particular airline mobile app despite using the website at least once a year. This indicates that using a website on a computer is still the preferred way of booking flights.

The users also reported that the website was more controllable than the mobile app. What they meant by controllable was that it was harder to accidentally make a mistake by hitting something unintentionally on the touch screen of the phone. This is an interesting finding since all of the participants were members of Generation Z who grew up using smartphones and touchscreen devices. This finding suggests that users do not want to risk making a mistake that could result in needing to pay a change fee as this particular airline charges \$200 to make a reservation change outside of a 24-hour grace period. The users also reported that they found that the website had more information readily available about the given flight options. Having more information available can lead to a more informed purchasing decision.

The users liked that both the website and the mobile app had a convenient sort function for sorting the various flight options. Both the website and the app allow a user to sort by the number of stops, price, departure time, arrival time, or total travel time. This function enables a user to find a flight that fits the user's demands easily. For example, a college student might sort by price while a business professional might sort by departure to find an early morning departure.

According to the data, users, on average, took less time to complete the series of tasks on the mobile app than the website. Tasks 4-6 were identical to Tasks 1-3, except for that they were being conducted on the app instead of the website. The combined time to complete tasks 1-3 on average was 4:56. The combined time to complete tasks 4-6 on average was 2:25 close to half the time. Users explained that the website had a long load time, which contributed to the longer time to perform the tasks. One user explained that more time was spent waiting for the website to load than actually completing the tasks.

Overall, despite the increased load time on the website, the users preferred the website over the mobile app. The ease of control by clicking definitive buttons and the fact that the main website provided more information to aid in the booking decision made it the clear winner. The main website allowed a user to compare fares for various flights and classes side by side. This made it easier to choose the flight of choice. The flight numbers and aircraft types are immediately made known. It also indicates whether the flights have internet and power plugs onboard.

Based on the results of this study, there are some recommendations that can be made to make the two booking platforms more user-friendly. The airline should make sure that the website is continuously being improved and that the load time should not take a long period of time. Additionally, the airline should make sure that its website does not crash during the loading time requiring the page to be refreshed. A system crash like this could reduce user trust in the airline. A user could conclude that the lagging website could be indicative of an unsafe airline. While this is not a logical conclusion, the user does not always act in a logical way.

The airline could also streamline its homepage so that a user does not have to scroll down in order to

find the booking function. Users also reported that the add special assistance link was hard to find, especially if they did not know what exactly to look for. This issue could be resolved if the airline turned that into a button rather than a hyperlink. This airline has a look of good ideas on both the mobile app and the website. If the website was redesigned with the strengths of the website and the speed and reliability of the mobile app, users say it would be a remarkable platform.

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## Factors Influencing Team Performance in the Flight Deck

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**Abstract:** The safe completion of a Part 121 regional airline flight requires that two pilots form a cohesive flight deck team. Aircraft are becoming more complex, and these advanced flight decks intersect with the emerging trend of today's regional airline crews exhibiting less experience due to factors such as high turnover within regional airlines and a shrinking pilot applicant pool from which to draw new hires. How well a less experienced crew identifies and mitigates threats posed by the human-machine interface is a measure of their overall performance. In addition, pilot performance relative to interaction with glass cockpit technology is influenced by overall Team Situation Awareness. Humans and machines do not always interact at an optimal level, and this report reviews literature to understand how Mutual Performance Monitoring, Crew Resource Management (CRM), and the formation of Shared Mental Models affect Team Situation Awareness and performance in a regional airline flight deck.

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### 1. INTRODUCTION

Regional jet aircraft equipped with glass cockpits such as the Embraer 175 and CRJ 900 present pilots a higher level of complexity than their analog gauge turboprop predecessors. This advanced technology has intersected with an emerging trend of today's regional airline crews exhibiting less experience due to factors such as high turnover within regional airlines and a shrinking pilot applicant pool from which to draw new hires (Smith, Hight & Smith, 2019). Regardless of a pilot's individual experience level or background, the safe completion of a Part 121 regional airline flight requires that two pilots form a professional and cohesive flight deck team.

How well a less experienced flight crew identifies and mitigates threats posed by their human-machine interface is a function of their overall situation awareness (SA) and performance. Indeed, humans and machines do not always interact at an optimal level of trust and competence (Musselman, 2019), and any deficiencies become a direct threat to flight safety.

This report examines human factors literature to explain Team Situation Awareness and pilot-machine interaction and how effective Crew Resource Management (CRM), Shared Mental Models, and Mutual Performance Monitoring can mitigate lower levels of pilot experience.

### 2. A REVIEW OF SITUATION AWARENESS (SA)

First, a review of SA is necessary to frame the contents of this report. Endsley (1995) provides a well-known and accepted three level definition of SA:

- Level 1 – Perceiving a situation
- Level 2 – Comprehending a situation
- Level 3 – Projecting the situation into the future

In simpler terms, a pilot exhibits SA when he or she understands what is occurring in his or her flight deck environment (Aydogan, Sharpanskykh & Lo, 2014).

Mission success requires that not only a pilot maintain SA of his or her roles and duties, but he or she must also do the same in the greater context of the other pilot's activities and responsibilities (Salmon et al., 2008). Therefore, if either pilot possesses incomplete or inaccurate SA of a situation or aircraft system, a breakdown in crew performance occurs (Endsley, 1995).

Assessing individual SA relative to system design is an established field. For example, the Situation Awareness Rating Technique (SART) measures how well a pilot understands system states, and the Situation Awareness Global Assessment Technique (SAGAT) assesses the pilot's performance of a task in relation to the three SA levels. Less developed, however, are means to measure Team Situation Awareness (Kaber & Endsley, 1998).

### **3. FORMING A FLIGHT CREW TEAM**

An understanding of the team environment in which pilots operate is important for understanding how well they will potentially work together. A typical flight crew team forms quickly (often the two pilots have never met), performs shared tasks, and dissolves upon successful completion of the flight duty period (Mathieu et al., 2000).

In addition, a flight crew depends on self-directed teamwork to attain the goals set by their organizational management (i.e. understanding of aircraft systems, adherence to standard operating procedure (SOPs), and safe, on-time arrivals) (Kauffeld, 2006). In order to achieve these goals, a crew depends on the rapid formation of a high-level trust in each other to perform tasks safely and competently (Mathieu et al., 2000).

Kauffeld (2006) identifies four team competencies driving trust:

- Professional – Using knowledge to identify and solve problems
- Methodological – The ability to find resources to accomplish tasks
- Social – The ability of a team to communicate and cooperate with each other
- Self-competence – How well a team fosters an environment conducive to growth

### **4. TEAM SITUATION AWARENESS**

Team SA covers several dimensions including individual SA, the SA shared by team members, and the sum of SA across all team members. The depth of individual pilot SA in turn influences overall Team SA (Salmon et al., 2008).

In addition to the previously mentioned team competencies, Bosstad and Endsley (1999) identify four components influencing Team SA:

- Shared SA Requirements – How well pilots understand which information about tasks and flight status needs to be shared
- Shared SA Devices – The displays or other means that pilots use to share information and communicate within the flight deck
- Shared SA Mechanisms – How well pilots use tools such as CRM and Shared Mental Models to interpret, comprehend, and project information
- Share SA Processes – How well pilots share SA, check each other's work, and coordinate and prioritize tasks

Shu and Furuta (2005) found that earlier studies of Team SA linking individual SA to team cognitive processes do not reach deep enough into examining how cooperative activity influences reciprocal team activities. Endsley's (1995) three level model of SA may accurately reflect the individual pilot's efforts on an objective level (Nonose, Kanno & Furuta, 2000), but overall Team SA is dependent on assessing the level of trust based interaction between the two pilots (Aydogan, Sharpanskykh & Lo, 2014).

Shu and Furuta (2005) further conclude that Team SA depends on an additional element of mutual beliefs that enhance the perception, comprehension, and projection of overlapping individual and group frameworks. Each pilot must develop a belief that the other pilot's cognitive and physical abilities are

proficient and competent enough to complete a flight mission (Nonose, Kanno & Furuta, 2000). Otherwise performance suffers due to a lack of team cohesiveness.

## 5. PILOT-MACHINE INTERACTION

While one would expect automation to lead to decreased workloads and increased safety, the opposite often occurs. Endsley (2015) believes this performance decrement arises from reasons beyond complacency. The typical regional pilot has become more of a systems monitor due to advanced interface designs such as the glass cockpit, and this leads to a more passive role for the pilot.

A passive pilot tends to exhibit decreased SA, increased training requirements, and sometimes an accident when interfacing with increased automation (Miller & Parasuraman, 2007). In fact, after studying 24 NTSB accident reports, Endsley (1995) found that a staggering 88% of human error resulted from SA deficiencies rather than poor decisions or issues with task completion.

Similar to Endsley's research, Musselman (2019) found that the ongoing interaction between pilots and aircraft in Part 121 operations leads to hazards and potential performance issues. He identified 123 Part 121 airline reports in the Aviation Safety Reporting System (ASRS) database that revealed human-machine interface hazards.

Musselman's research (2019) confirmed that more incidents occur during the takeoff and landing since these phases require more pilot-machine interaction to configure systems. Mental models related to automation interface and SA related to tasks and demands are the most likely human factors to be negatively influenced by the human-machine interface.

Musselman's findings also relate to Endsley's work (2017) developing the concept of the human-autonomy system oversight (HASO) model. The HASO model places attention allocation at its core, and from there designers determine an optimal level of pilot-aircraft automation interaction. How well the automation performs influences the pilots' trust in it and ultimately the level of individual and team SA they devote to it.

## 6. CREW RESOURCE MANAGEMENT

Effective Team Situation Awareness is maintained when both pilots form a joint understanding of a given situation (Salmon et al., 2008). Traditional Crew Resource Management (CRM) emphasizes concepts such as open communication to trap and prevent errors. CRM is generally presented on a theoretical level in the classroom with the hope that crews will successfully utilize it on line to maintain SA along all three levels (Holt, Boehm-Davis & Hansberger, 2000).

Major disadvantages to teaching CRM on a theoretical level in the classroom are that a crew may not fully understand CRM concepts or inexperienced pilots could incorrectly apply it when addressing a previously unseen situation such as diagnosing an errant system (Holt, Boehm-Davis & Hansberger, 2000).

With these shortcomings in mind, Ikomi et al. (1999) tested with encouraging results at a regional airline an interesting enhancement to traditional CRM called Advanced CRM (ACRM). CRM is defined by principles, and this ACRM study turned these principles into specific and observable actions written into the airline's Standard Operating Procedures (SOPs), Flight Operations Manual (FOM), and Quick Reference Handbook (QRH) (Holt, Boehm-Davis & Hansberger, 2000).

Ikomi et al.'s study followed 50 crews divided into traditional CRM and ACRM participants to observe their performance. The best performing crews utilized ACRM as SOP, and this study indicates that ACRM leads to a higher level of team SA (Holt, Boehm-Davis & Hansberger, 2000). ACRM is a potential application to mitigate decreased pilot experience levels at a regional airline by utilizing heightened standardization at a procedural level.

## 7. SHARED MENTAL MODELS

CRM's principles of communication, task management, and team cohesiveness become even more effective when combined with shared mental model structures (Reynolds & Blickensderfer, 2009). Salmon et al. (2008) describe the relationship between Endsley's three level model of SA and the role of mental models in achieving and maintaining SA. A pilot develops mental models through his or her training and experience. The depth of experience and effectiveness of training will determine how proficiently an inexperienced pilot notices critical cues from an aircraft system (Level 1), how well he or she processes these cues to understand their meaning (Level 2), and the accuracy he or she can predict a future state of the system (Level 3).

Mental models also provide a means for pilot-machine interaction by structuring their individual knowledge into patterns. A shared crew mental model is the extent which individual pilot mental models overlap with each other as the pilots form their team to complete tasks or interface with the aircraft (Reynolds & Blickensderfer, 2009).

The increased technology in regional aircraft has led to an increase in task complexity. Mathieu et al. (2000) found a link between shared mental models and team performance while studying 56 teams flying simulated combat missions on a desktop flight simulator. Much like some less experienced regional airline crews, Mathieu et al.'s study examined novice participants performing complex tasks. The study provides evidence that the depth and similarity of knowledge shared by two pilots does determine how well they perform as a team regardless of experience level.

Bosstad and Endsley (1999) also tested shared mental models in relation to how well a team develops SA by studying sixteen teams of two. One group of teams was provided their counterpart's job description and time to ask each other questions. The other set of teams was given only information regarding their individual tasks. Teams were then assigned to shared displays or non-shared displays. The highest performance levels came from teams with either shared displays or shared mental models. Non-shared displays and no mental model teams exhibited a highly noticeable performance decrement.

SA is the state in which pilots find themselves at any given time during a flight, and mental models provide information from a pilot's long term memory to aid in comprehension (Level 2) and projection (Level 3) (Endsley, 1995; Aydogan, Sharpanskykh & Lo, 2014). Therefore, a regional airline crew's overall Team SA and Shared Mental Model are directly affected by the experience of either pilot in terms of how developed his or her knowledge is.

## 8. MUTUAL PERFORMANCE MONITORING

Mutual Performance Monitoring in the flight deck occurs when each pilot can effectively handle his or her own tasks while monitoring those of the other pilot at the same time (Albon & Jewels, 2012). Decreased experience at the regional level combined with Musselman's (2019) and Endsley's (2017) investigations into pilot-machine interaction indicate catalysts for a potential accident resulting from automation, decreased Team SA, and ineffective Mutual Performance Monitoring.

Shu and Furuta's (2005) found that mutual awareness and its advanced state, Mutual Performance Monitoring, evolve either directly from two way verbal communication or are inferred implicitly by non-verbal communication. Albon and Jewels' (2012) research also affirms the importance of communication by explaining how Mutual Performance Monitoring ties in with Endsley's (2005) SA model. Study participants were better able to perceive what others were doing (Level 1 SA), comprehend what progress teammates were making (Level 2 SA), and project any changes that might need attention (Level 3 SA) once they understood the importance of monitoring each other's work.

One interesting aspect of Mutual Performance Monitoring relates to shared mental models. Each pilot does not necessarily need all of the information and knowledge to complete mutual tasks such as understanding the underlying causes of an aircraft system fault since complementation and robustness can overcome gaps (Nonose, Kanno & Furuta, 2009).

Complementation allows for some knowledge and skills to be distributed across the crew. What one inexperienced crewmember may lack is made up for by the other who possesses it. Furthermore, robustness defines how well a pilot reacts to stress, failures of a system, or other high workload events such as configuring an aircraft for landing or takeoff (Nonose, Kanno & Furuta, 2009).

With both pilots engaged as a team monitoring each other's performance, one of them can detect a system failure or aircraft misconfiguration the other may not perceive (Nonose, Kanno & Furuta, 2009). Though a pilot lacking any procedural knowledge or experience is not the best situation, a crew properly backing each other up can overcome some minor aspects of inexperience.

## **9. AN INTERESTING LIMITATION ON CREW PERFORMANCE AND TEAM SA**

This report has thus far explored the positive contributions CRM, Shared Mental Models, and Mutual Performance Monitoring make towards an inexperienced regional airline crew's interaction with technology and/or Team SA. One dynamic not easily overcome is the human element. No amount of ACRM or HASO modeling can fill the safety vacuum created by a crewmember who does not use CRM principles to speak up when he or she notices an issue.

In fact, the NTSB found that in 37 accidents between 1978 and 1990, the failure of the First Officer to speak up contributed to 84% of them. Another analysis of 19 accidents between 1991 and 2000 found a failure to speak up in 68% of them (Bienefeld & Grote, 2012).

Bienefeld and Grote (2012) interviewed 1,751 pilots and flight attendants at a European airline to look for causes of crewmember silence. Overall these crewmembers stated that they spoke up in only about half of events warranting a CRM intervention.

Bienefeld and Grote's research found that the main reason for a Captain's failure to speak up is his or her desire to maintain a positive team atmosphere with the First Officer. The main reason for a First Officer's failure to speak up is the fear of harming a relationship with the Captain and damaging the team atmosphere. This hesitancy is in spite of pilots recognizing that speaking up is paramount for Team SA and safety.

CRM is the primary way pilots are trained to facilitate communication, teamwork, and task management and is required by all 193 International Civil Aviation Organization (ICAO) member states (Reynolds & Blickensderfer, 2009; Member States, 2019). Given the importance of CRM, the study's results are shocking since effective team performance depends on the safe completion of technical tasks and team processes based on CRM and Shared Mental Models (Bosstad & Endsley, 1999).

## **10. A CAUTIONARY TALE OF TEAM SA FAILURE**

Colgan Flight 3407 is one of the most high-profile regional airline crashes in recent times and resulted in the deaths of all 49 on board and one person on the ground as it approached the Buffalo Airport on February 12, 2009. The aftermath of Flight 3407 revealed shortcomings in areas such as pilot proficiency and CRM and led to an increased regulatory focus on pilot licensing and training (Zremsky, 2019).

NTSB Chairman, Robert L. Sumwalt (2010) provides an overview of the accident, and we can relate the crash of the Dash 8-400 aircraft to the ideas presented in this report regarding team SA:

First, the crew lacked a Shared Mental Model of flight in icing conditions. The Captain set icing speeds for landing and the First Officer non-icing. This discrepancy led to the First Officer unknowingly monitoring speeds below the stall threshold in the icing conditions. Second, neither the Captain nor First Officer noticed the rising low-speed cue in their instrument scans, thus indicating a lack of mutual performance monitoring. Third, the Captain did not instill a strong CRM environment as evidenced by weak leadership and violation of sterile cockpit. Finally, the Captain did not interact correctly with the Dash 8's technology when he pulled repeatedly against the stick pusher rather than correctly reducing angle of attack to break the stall.

## 11. CONCLUSION

The measurement of individual SA using methods such as SART and SAGAT is a well-developed domain. A reliable system to evaluate team SA at a regional airline level relative to flight crews and their interaction with flight deck systems is an opportunity for future research. In the absence of effective assessments of team SA, our question becomes, “How can we ensure that crewmembers maintain a high level of team situation awareness while completing systems oriented tasks?”

One way forward is through Federal Aviation Administration (FAA) initiatives such as Advanced Qualification Program (AQP) and Line Operations Safety Assessments (LOSA) that provide data points to regional airlines to determine the efficacy of training and crew coordination, respectively. Finally, regional airlines can enhance training and awareness in areas such as Mutual Performance Monitoring, Crew Resource Management, and Shared Mental Models to mitigate lower levels of experience and to better monitor the human interaction with technology.

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## Application of Tripod Incident Analysis in Aviation

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**Abstract:** The purpose of this research was to investigate literature review to explore the history of Tripod Incident Analysis, components of the Tripod Incident Analysis method, accident analysis, and human error that includes a discussion on the Human Factors Analysis and Classification System (HFACS).

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### 1. INTRODUCTION

The purpose of this research was to investigate industry applications for tripod incident analysis. Literature was reviewed and exploratory research into Tripod Incident Analysis software was examined. The literature review consisted of the history of Tripod Incident Analysis, components of the Tripod Incident Analysis method, accident analysis, and human error that includes a discussion on the HFACS. The IncidentXP Software was explored in building Tripod diagrams to test the software capabilities in identifying the root cause of accidents (CGE Risk Management Solutions, n.d.). The Tripod Incident Analysis method has its foundations in the Swiss Cheese Model (Reason, 1990). The Swiss Cheese Model primarily focuses on risk management through focusing on barriers within an organization between the cause of harm or undesirable outcome and the outcome itself. In the Tripod methodology, the triggers for the sequence of occurrences leading up to an undesirable outcome are observed and documented. The analysis focuses on understanding, investigating and determining how the incident transpired, and which defenses or barriers failed to prevent the incident and why (Kianfar, Fam, & Faridan, 2010). While the prominent cause of aviation accidents has changed from mechanical factors to human factors, the method of investigating and analyzing aviation accidents has also evolved. Based on the different types of human error models, the Tripod methodology provides another option for researchers to use in the identification of root cause analysis of incidents and accidents internal and external to the aviation industry.

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## 2. LITERATURE REVIEW

### 2.1. Incident Analysis History

Causal analysis or incident analysis involves applications of various methods and techniques to prevent or mitigate risks. This analysis also focuses on the reoccurrence of incidents through obtaining comprehensive knowledge and understanding of these occurrences. There are several known conceptual methods and techniques preeminent in incident and causal analysis such as Barrier Analysis, Change Analysis, Management Oversight and Risk Tree or Management Oversight and Risk Tree (MORT), and other causal analysis methods that leverage trees, checklists and charts (Pranger, 2014).

In the late 1980's and early 1990's, Shell International allocated funding for academic research aimed at understanding the contribution of human factors in incidents and conducting a more comprehensive root cause and immediate cause analysis of incidents. Universiteit Leiden and Victoria University, Manchester conducted this research. The by-product of this research was the Swiss Cheese Model and ultimately the Tripod Beta method, which builds upon the former (Reason, 1990; Energy Institute, 2015). Tripod Beta method is an advancement and extension of the Swiss Cheese Model, it is also appropriate to regard it as the culmination of other distinguished techniques such as the fault tree and barrier analysis (Pranger, 2014). The tripod methods not only facilitate the identification of human error that ultimately led the incident, but also explores the external factors and influences that induce these human errors (Energy Institute, 2015).

### 2.2. Components of Tripod Incident Analysis Method

The Tripod Beta incident analysis methodology focuses on the triggers for the sequence of occurrences leading up to an undesirable outcome. These triggers are observed and documented. The analysis focuses on understanding, investigating and determining how the incident transpired, which defenses or barriers failed to prevent the incident, and why (Kianfar, Fam, & Faridan, 2010). Being a synthesis of the fault tree and barrier analysis techniques, the Tripod Beta method utilizes a conceptual tree structure to be representative of the incident mechanism, events and their subsequent interrelations (Mansouri, Fam, & Nikoomaram, 2014).

The tree structure is built up based on critical components such as the Object or Target, the Agent or Hazard, the Event, the Barriers, and extended branches. The tree represents the Causal Path if and when the barrier fails (Kianfar, Fam, & Faridan, 2010). The event is the subsequent result of an unwanted interaction between the agent and the object. The barriers or defenses employed by an organization or entity seek to prevent such interaction leading to an event. When the barriers do not hold or fail, the causal path helps investigators and analysts to determine how and why this is the case. When there is a failure of the barrier, the causation path works its way to unravel all the causes. By commencing the causal analysis at the active failure, the analyst works back through the control and defense failures and shallow failures. Then, the analyst determines the preconditions under which these failures occurred and traces back to the underlying or latent failures that helps to determine all the causes and occurrences that resulted in the failed barrier (Poursoleiman, Fam, & Derakhshanjazari, 2015). One example for the Tripod Beta Incident Analysis method using the tree is that the agent is a hot pipe work, the object is the operator and the event is the operator getting burnt as a result of failed controls, defenses, or the barrier. The organization and association then derive the causal paths that led to the agent-object interaction (Kianfar, Fam, & Faridan, 2010). Such in-depth analysis using the Tripod Beta tree is driven primarily by the Tripod theory. The hypothesis of the theory is engrained in the belief and assumption that the active failure of the defenses does not occur in isolation but instead there are multiple triggers and occurrences that cause it (Poursoleiman, Fam, & Derakhshanjazari, 2015). In this particular method, there is a strong presumption of the role of human error in triggering events and incidents, and the role of preventable external factors have on the cause of such errors (Kianfar, Fam, & Faridan, 2010). The tree is therefore structured in a way that provides a dynamic outlook of the incident to help prevent reoccurrence of similar incidents in the future.

In summary, the agent, object and event form the core of the Tripod Beta Tree, which further extends or branches out into identifying the failed barriers and their inherent causes. The incident investigation and analysis using the tripod beta technique outlined above is preceded by obtaining the initial findings and collecting evidences. It is succeeded by preparing a documented report with results, discussions, recommendations and suggestions to make this method useful in incident or accident prevention (Energy Institute, 2015).

### **2.3. Accident Analysis**

Air transportation is a highly demanded form of transportation. The International Air Transport Association (IATA) expects that by the year 2036, approximately 7.8 billion passengers will travel through the use of flying (IATA, 2017). This constant increase in passengers solidifies the need for thorough and efficient safety programs in the airlines (Liou, Tzeng, & Chang, 2007). The challenge with the industry, that the Federal Aviation Administration or any other civil aviation organizations faces, is that aviation is already a very safe industry (Shappell et al., 2006). While it is considered a safe industry, accidents still occur resulting in the loss of life. A significant amount of accidents or incidents in aviation are attributed to human error. Shappell and Wiegmann (1996 as cited in Shappell et al., 2006) identified that about 60% to 80% of aviation accident are due to human error. According to Shappell et al. (2006), most studies have focused on pilot demographics or situational factors instead of deeper human error causes. In the earlier days of aviation, the focus of accidents was mechanical issues or a flight crew's physical skill deficiencies (Li & Harris, 2006). However, the focus has now expanded to organizational issues or human factors issues such as decision-making, supervisory factors, attitudes, and organizational culture.

### **2.4. Human Error**

As aircraft have become more reliable in terms of mechanical or engineering failures, human error has been more common in aviation accidents. Wiegmann and Shappell (2001a) identify the multiple human error perspectives found in the aviation industry; cognitive, aeromedical, psychosocial, ergonomics and systems design, and organizational. Cognitive human error lies in the process of information progress through a series of mental operations or stages. Errors occur when information does not properly process in one of the stages such as "attention allocation, pattern recognition, and decision making" (Wiegmann & Shappell, 2001a, pg. 343). The aeromedical perspective suggests that human errors are due to the many different aeromedical factors that can impact a human such as "hypoxia, dehydration, fatigue, spatial disorientation" (Wiegmann & Shappell, 2001a, pg. 346). These factors are also often due to jet lag, alcohol, medication, smoking, and illness. Psychosocial factors include the social aspects of flight operations. Most commercial aircraft (i.e. Part 121 operations) are not single pilot operations but consist of an entire flight crew. While this is usually considered internal interaction, there is also a lot of external interaction of the flight crew with air traffic controllers, ground crew, company dispatch, and even flight attendants (Wiegmann & Shappell, 2001a). Due to the multiple different channels of communication and complexity of the aviation industry, the psychosocial perspective is a critical aspect to reference when investigating human error in aviation accidents. In ergonomics and systems design, technological aspects are viewed alongside the human element. The Software, Hardware, Environmental conditions, and Liveware (SHEL) model is a common tool used to describe the components that are necessary for any type of successful human-machine system design (Edwards, 1988, as cited in Wiegmann & Shappell, 2001a). The four basic components of SHEL are interacting factors that come together in the aviation industry and especially in the cockpit. The final piece of the perspective puzzle is the organizational factors that impact human error. Aircraft accidents are very complex in nature and are never only due to one factor. Bird's Domino Theory (1974, as cited in Wiegmann & Shappell, 2001a) prefaces that an accident occurs when the "dominoes" are correctly lined up in a sequence and each error "topples" over to the next. These dominoes start with the organizational factors, such as safety culture and if there is a problem at the higher level then it will affect the lower levels. This is in line with Reason's Swiss Cheese Model (1990) which is the primary foundation for HFACS established by Shappell and Wiegmann (2000). HFACS splits human error into four levels:

organizational influences, unsafe supervision, preconditions for unsafe acts, unsafe acts of operator. The first three groups can be considered more latent errors, whereas unsafe acts of the operator are where active failures of human error occur (Reason, 1990; Shappell & Wiegmann, 2000).

HFACS allows researchers to take vital information such as the probable cause issued by National Transportation Safety Board (NTSB) reports and apply this information to new safety systems, manufacturing procedures or practices, training, and more to help prevent future accidents. Shappell and Wiegmann (2003) specify that information such as gender, age, or flight hours do not help increase aviation safety. Wiegmann and Shappell are foundational leaders in human factors analysis and have completed many studies in the application of HFACS. Most studies that use HFACS as a way to analyze accidents, make use of the publicly available data provided by the NTSB and also investigation reports from the FAA's National Aviation Safety Data Analysis Center (NASDAC). By using the final report information on probable cause and contributing factors, "raters" can organize the different accidents based on HFACS categories. The highly technical data used for the HFACS analysis on these aviation accidents requires that "raters" have a very strong background in aviation and are familiar with its terms. Most likely due to the aeronautical aspect of these studies, pilots were used to categorize the data into the HFACS hierarchy. The downside to having pilot-raters as stated as a limitation by Shappell et al. (2006) is that pilots are not always current with or experts in human factors or psychology. Having pilots trained in HFACS is one step to help ameliorate the differences that could potentially occur between pilot-raters when compared with psychology based-raters.

Shappell and Wiegmann (2003) took a look at general aviation (GA) accidents that occurred between 1990 and 1998 and analyzed them using HFACS. Using "pilot-raters" who coded the data from 14,571 GA accident reports, it was determined that skill-based error, decision errors, and perceptual errors were the main contributing factors that led to GA accidents. In fatal accident cases, violations of regulation or rules were more common compared to the non-fatal GA accidents. Shappell and Wiegmann also determined that there was not a significant difference in the types of unsafe acts based on regional differences. While commercial aviation accidents can occur frequently, GA accidents "happen virtually every day" (Shappell & Wiegmann, 2003, pg. 1). Similar to previous analyses, Wiegmann et al. (2005), found when analyzing more than 14,000 GA accidents from 1990 to 2000, that skill-based errors, decision errors, and perceptual errors were factors in about 80%, 30%, and approximately 10% of accidents studied respectively. These numbers further build upon their previous studies of how important human factors are when it comes to accident analysis. Knecht and Lenz (2010) determined that while adverse weather still accounts for a high number of GA accidents, weather alone is not always the only contributing factor. By analyzing incidents, which are much more common than accidents, more salient causal factors were determined. Knecht and Lenz (2010) did not use HFACS to analyze incidents but instead used information directly from pilots who reported weather-related incidents. This is a potential area of focus for also using the HFACS Model.

While the original HFACS tool was first applied to military aviation, Wiegmann and Shappell (2001) applied their HFACS model to human error in aircrew-related commercial aviation accident. By analyzing these accidents, that occurred during the years of 1990 and 1996, the findings suggest that the model is a useful tool to study and categorize human error in aviation accidents in the civilian industry. By using two investigation report sources (NASDAC and the NTSB), Shappell et al. (2006) suggest that the majority of the accident causal factors in commercial aviation, 14 CFR Part 121 air carrier and 14 CFR Part 135 commuter, were due to aircrew issues or the environment, whereas supervisory and organizational causes were not as frequent. Physical environment is a condition under preconditions of unsafe acts under HFACS and skill-based error and decision errors that fall under the unsafe acts of the operator under HFACS.

Figure 1 displays a sample Tripod Diagram using IncidentXP software that was explored to test the software capabilities in identifying the root cause of accidents (CGE Risk Management Solutions, n.d.). In Figure 1, the flawed component was the root cause of accidents. The precondition is the influencing factor for the root cause which is the inadequate inspection. The immediate cause is the substandard act, which in the case of Figure 1, is that previous inspection found issues. NTSB accident reports were used to test the software capabilities (NTSB, 2011). NTSB provides publicly available accident reports that include details about the accident or incident, analysis of the factual data, conclusions derived from the investigation

experts, and then also states the probable cause and contributing factors of the accident. The Tripod Diagram provides researchers with a method to visually display what happened in regards to an accident, how did the accident occur and why did the accident occur.

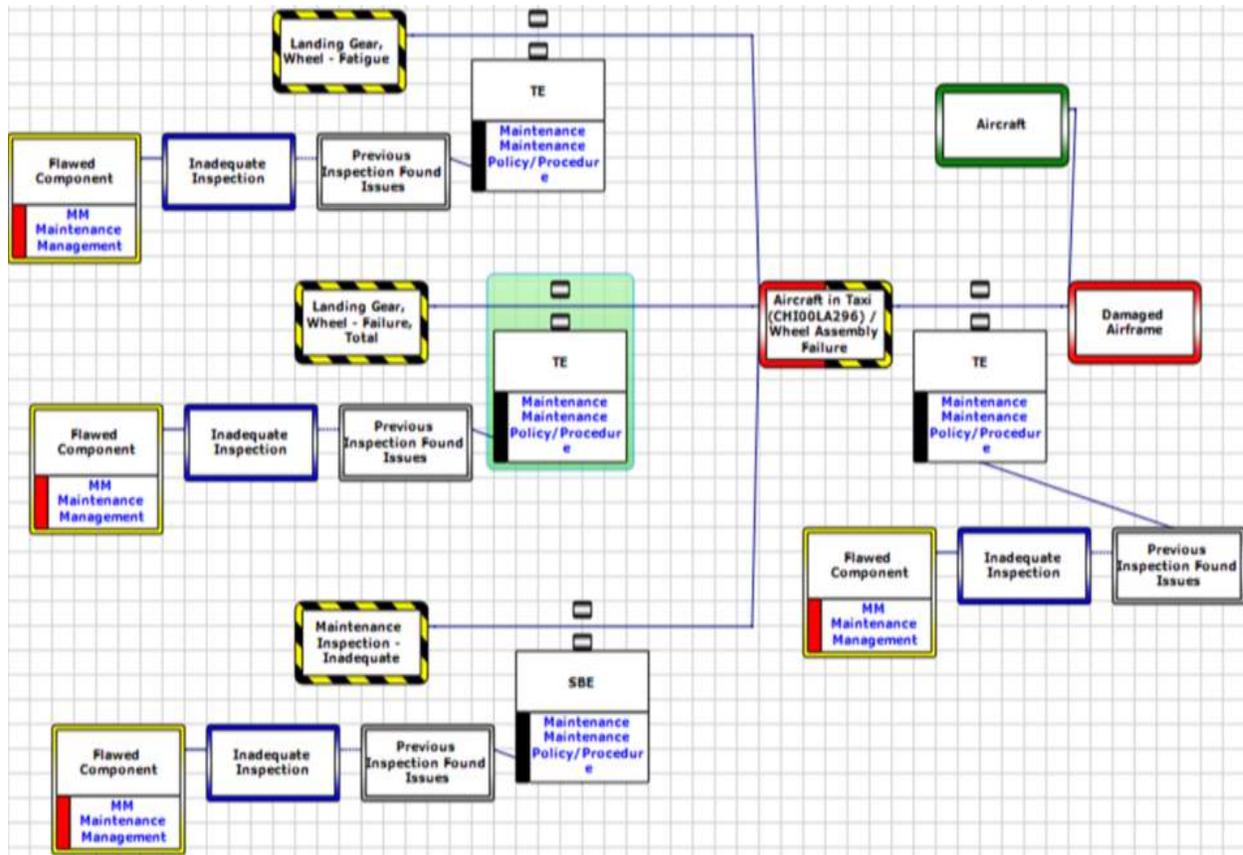


Figure 1. Tripod Diagram

Yan and Histon (2014) used HFACS to categorize airline accident and incident reports from the NTSB and the Transportation Safety Board of Canada. These reports were from 2006 until 2010. The research suggests that approximately 61% of the 267 reports were related to human error. Similar to previous results (Shappell et al. 2006), the results suggest that Unsafe Acts and Preconditions of Unsafe Acts were the most prominent human factors risks when it came to accidents and incidents of airlines in North America. A trend analysis was also completed that indicated that the number of accidents or incidents due to violations was on the rise. Furthermore, the findings suggest that Crew Resource Management (CRM) is a prominent causal factor as well as a lack of training (Yan & Histon, 2014). Kharoufah, Murray, Baxter, and Wild (2018) found that the most significant human factor that affected commercial air transport accident and incidents was situational awareness followed by non-adherence to procedures. The research suggests that accidents such as Air Asia 8501 and Air France 447 were the result of human factors. Daramola (2013) suggests that after applying HFACS categories to 45 accidents, that occurred in Nigeria during the years of 1985 until 2010, skill-based errors were one of the most occurring categories. Following skill-based errors, physical environment (i.e. weather conditions) followed by inadequate supervision. Daramola classifies many inadequate supervisions categorized accidents as due to when a commander (usually an aircraft crew captain) gives instructions or makes decision that led to an accident. While some accidents were due to flight crew captains making inadequate decisions, some were also due to maintenance oversights. One cited

example includes a Concorde Airlines accident that occurred in 1990 where a supervisor did not cross-check maintenance records which led partly to the crash. Li, Harris, and Yu (2008) used HFACS to analyze 41 civil aviation accidents that involved aircraft registered to the Republic of China. The research suggests that the HFACS categories of precondition for unsafe acts, unsafe supervision, and organizational influences each had statistically significant relationships. These accidents that were studied between 1999 and 2006 led to a discovery of the “routes to failure” which is the primary reason that HFACS is a great tool to help prevent future accidents in the aviation industry.

### 3. CONCLUSION

While the cause of aviation accidents has changed from mechanical factors to more human based factors, the way of investigating and analyzing aviation accidents has evolved. Based on the different types of human error perspectives and other models of human error such as the Domino Theory and the Swiss Cheese Model, the HFACS is a tool used by researchers internal and external to the aviation industry. The use of HFACS can be helpful to safety organizations to re-evaluate current regulations, industry standards, or even organizational procedures. By analyzing accidents or incidents, the aviation industry can move from reactive types of analysis or change to a proactive analysis where aviation safety is continuously monitored and adjusted as necessary. Software, such as IncidentXP software, is also a useful tool for researchers to visually display information on accidents such as what happened, how did it happen, and why did it happen (CGE Risk Management Solutions, n.d.).

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# Drivers and Barriers of Advanced Manufacturing Technology Implementation in Saudi Arabia

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**Abstract:** The purpose of this paper is to present a systematic literature review to identify opportunities and challenges that face Advanced Manufacturing Technology (AMT) adoption in Saudi industrial sector. It also highlights the critical factors behind those opportunities and challenges, which need to be taken into consideration when it comes to AMT implementation. This study uses a systematic review of the literature contained in the two databases ProQuest, and Compendex and on the search engine Google Scholar. Moreover, the study highlights a gap in the research efforts for identifying the need for effective integration and interaction between the eight different categories mentioned previously for both developed and developing economies. For that reason, it is recommended that researchers adopt a broader view that includes the role of integration and interaction between critical factors in each category and their impact on AMT adoption. The systematic literature review in this study used to review all vital elements of adopting AMT and identifies new research avenues and different approaches to implementing AMT, focusing on the integration between the different categories that can be used for AMT adoption in Saudi Arabia.

*Keywords:* Advanced Manufacturing Technology, Systematic literature review, implementation, Adoption, Drivers, Barriers, Success Factors, Challenges, Saudi Arabia.

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## 1. INTRODUCTION

The industrial transformation in any country can be driven by adopting advanced manufacturing technologies so, and it is more practical to consider AMT adoption as an engine of any industrial change. The critical factors which have an impact over AMT adoption in one area of the industry also can be the same in any other areas that rely on technology to run that industry. From a more comprehensive view of the topic, AMT adoption is related to the rapid growth of technology. It can be considered as an umbrella that contains a variety of different types of manufacturing and industry applications underneath it.

Lately, the Saudi government launch its strategic vision for the year 2030. According to the vision official document, the Saudi government is preparing itself for massive industrial transformation. The national industrial development and logistic program of the vision 2030, is considering the development of the industrial sector to be somehow risky because of the uncertainties associated with the AMT that can be implemented to achieve that goal. For that reason, research efforts should be more focused toward uncovering those uncertainties by determining the drivers and barriers of AMT adoption in the country.

## 2. REVIEW OF THE PREVIOUS STUDIES

Most of the earlier studies covered in this literature review focus on AMT from different dimensions. These dimensions represent the boundaries that every country should take into consideration to adopt AMT successfully. The proposed classifying of aspects in this study are planning, management, business,

technical, economy, society, policy, and environment. The following part will discuss each one of the eight dimensions.

### **2.1. Planning for Implementation**

Planning for appropriate adoption of advance manufacturing technology is a challenging matter. Adequate planning would pave the road into the successful implementation of advanced manufacturing technology. Regardless of the manufacturing applications and to which area they belong to, the planning efforts would lighten the path toward desired results and outcomes in addition to uncover any ambiguities and uncertainties (Chen and Small 1996). With focusing on competitiveness, many firms or organizations would give the planning stage the highest priority throughout any AMT project's life cycle. Planning for AMT adoption include four main stages, which are; strategic planning, justification; training and installation; and implementation (Chan, Chan et al. 2001).

Planning efforts toward the appropriate installation of the technology are critical matter because it determines the actual utilization of the technology (Small 2007). Planning activities must consider giving enough room for innovation. While putting plans in place, the innovation part is mainly concerned with the impact of AMT diffusion and transfer, in addition to concentrating on the effective adoption of the technology (Rhodes and Wield 1994). The ability to make a positive change in different aspect is also a critical role in the planning process where the direction of the shift determined according to desired outcomes and results (Small 2007).

### **2.2. Managing the implementation**

Management approaches are playing a critical role in the adoption of advanced manufacturing technology. Management experience and knowledge about AMT are crucial factors for successful adoption and implementation (Chan, Yusuff et al. 2015). In addition to that, having a clear picture, and foresight of the AMT history and future can be considered as a strong point for any effective management practices. It is possible to say that any successful implementation of AMT requires firms and organizations to have a workforce with a higher level of qualifications and skills in addition to a flexible organizational structure that supports and induce the changing process (Yu, Shen et al. 2011).

The main focus of any management approach, which is designated to assure a successful implementation of AMT, is the change process. It is commonly known that there is a high risk on any transformation efforts desired by any firm or organization unless there is an awareness of the requirements to make that transformation less risky. Furthermore, the changing process which is used for the adoption of AMT requires appropriate changes in the firm's and organization's structure and infrastructure in addition to keeping up with performance enhancements to improve the capability (Saber, Yusuff et al. 2010). Furthermore, When a firm or organization decides to adopt or implement AMT then, it becomes crucial to evaluate the feasibility of changing process. Moreover, it should know the situations in which it is preferable to current manufacturing systems (Beatty 1992).

### **2.3. The Business behind AMT Adoption**

From a business perspective, utilization of AMT is considered as a critical factor which helps manufacturing firms around the world to reduce manufacturing costs, improve the quality of their products, increase the desired outcomes as well as production flexibility, in addition, to help with maintaining and enhancing their competitiveness on global markets (Hynek, Janeček et al. 2009). One of the main concerns when it comes to AMT adoption and implementations in return on investment. Firms are mainly focusing on the amount of money they can make when applying new manufacturing technology with makes AMT grows very fast in the last couple of decades in addition to the stability and growth of the technology itself (Chung 1991). However, other firms are finding themselves forced to adopt AMT because of the competitiveness pressure they face in a specific market (Percival 2009).

Generally speaking, it is possible to say that implementing a competent AMT can be considered as a key to enter a new market segment or to maintain a share of the current market. In addition to that, AMT offers an opportunity for firms to gain a competitive advantage to make them sustainable over a long-term timeframe (Sohal 1997). Moreover, at the heart of this technology-driven manufacturing lie the necessities of competition and scarcity of resources. However, not only are companies always under pressure to produce more with less but, at the same time, make things better and bring them to market faster than their competitors (Khan and Nasser 2016).

#### **2.4. The Need For Technical Capability**

There is always a kind of healthy relationship between firms' performance and their technical abilities. In most cases, higher performance is driven by high technological capacity which leads firms to maintain its performance at a high level or keep increasing their technical capabilities through joint ventures or licensing agreements (Singh and Khamba 2008). During the selecting phase of AMT adoption, it is necessary to specify what the new technology is capable of and wither the firm's worker are capable of dealing with it or not. In other words, the management is encouraged to answers some questions regarding the technical requirements of the adopted AMT (Bessant 1985). It is also a critical matter to assesses the technical capabilities of the technology itself and the firm workforce and how the two parts should react.

The technical strategy has to cover every technical process aspect of the implementation and at the same time, determine the technical requirements for adoption of the AMT (Dawson 1996). However, some firms and companies have a kind of similar strategy which is called utilization strategy, and the only difference is that some utilization strategy doesn't include a clear role for the firm's workforce (Chung and Swink 2009). So, it is necessary to have the human efforts involved in the technical strategy to avoid any conflict between the workforce and the technology (Co, Eddy Patuwo et al. 1998).

#### **2.5. The Economic Side Of AMT Adoption**

As an essential source of income for any national economy, the industrial sector cannot achieve any success on its own without relying on other sectors in the country. There has to be some kind of harmonious relationship of shared interests between industry and other leading sectors of the national economy. Moreover, the development of an industrial sector might be a result of the development of other sectors (Dawson 1996). Also, the development of the industrial sector might lead to the development of other sectors. Adopting AMT as an engine for industrial development would be a wise decision because of the enormous benefits that national economy gains from this process (Sharma, Dangayach et al. 2008)

#### **2.6. Social Impact Of AMT Implementation**

The social part which covered in previous studies considered as a practical contribution which used to determine how the society reacts towards AMT adoption. Highlighting the human factor impact on AMT adoption is essential to develop an effective implementation strategy for AMT (Co, Eddy Patuwo et al. 1998). Most of the studies that cover the social part of the topic have linked social awareness to the performance of any organization that adopts AMT, where high social awareness leads to high performance and vice versa (Chung 1996). Furthermore, cultural barriers are playing an essential role in adopting any new technology and should be dealt with carefully when considering the social aspect of any implementation efforts (Majchrzak 1988)

#### **2.7. Polices And Regulations Associated With AMT Adoption**

Adopting new technologies for manufacturing purposes could be a challenging issue when there are no policies or regulations to organize every aspect of the matter. Policies formulation is a critical step of AMT adoption, which might determine the capability of an organization to achieve successful implementation of the technology (Park 2000). Moreover, the flexibility of these policies and regulations should be taken into

consideration to make considerable space for any innovation efforts (Small and Yasin 1997). Also, it is necessary to make continuous evaluation and updates to these policies based on the feedback process.

### 2.8. Environmental Awareness Of AMT Implementation

Taking environmental precaution when adopting AMT is not a luxurious matter anymore, but rather a necessity. Noticing how the industry has negatively impacted the environment throughout the years makes it an ethical role for any decision-maker to consider environmental impact when deciding which AMT to adopt (Szalavetz 2017). So, with high environmental awareness from all stakeholders affected by the AMT, it is possible to adopt an environment-friendly AMT.

### 3. PROPOSED METHODOLOGY

This study consists of a systematic review of the literature, which is quite an innovative method in the social sciences and not frequently used in AMT studies. Furthermore, this study uses a systematic review of the researches contained in the two databases ProQuest, and Compendex and on the search engine Google Scholar by using keywords search to enhance the overall quality of the review by minimizing bias which included in all published research. The following table shows the different search phases.

**Table 1: Systematic review search, keywords, and results**

Search Phase	ProQuest	Compendex	Google Scholar	Total
All articles containing at least one of the following keywords in their abstract or title: AMT AND EV AMT AND Success factors AMT AND Challenges AMT AND Barriers AMT AND Adoption AMT AND Implementation AMT AND Saudi Arabia	1,282	864	1,822	3,968
All articles containing at least one of additional keywords in their abstract or title: Country, economy, firm; company; organization	417	327	746	1,490
All articles whose abstract content was substantively relevant (fit for purpose)	122	184	231	537
All articles whose text was effectively relevant (fit for purpose)	41	33	19	93

To decide which article can describe as “Fit for Purpose”, the literature searching process conducted according to the following Eligibility Criteria.

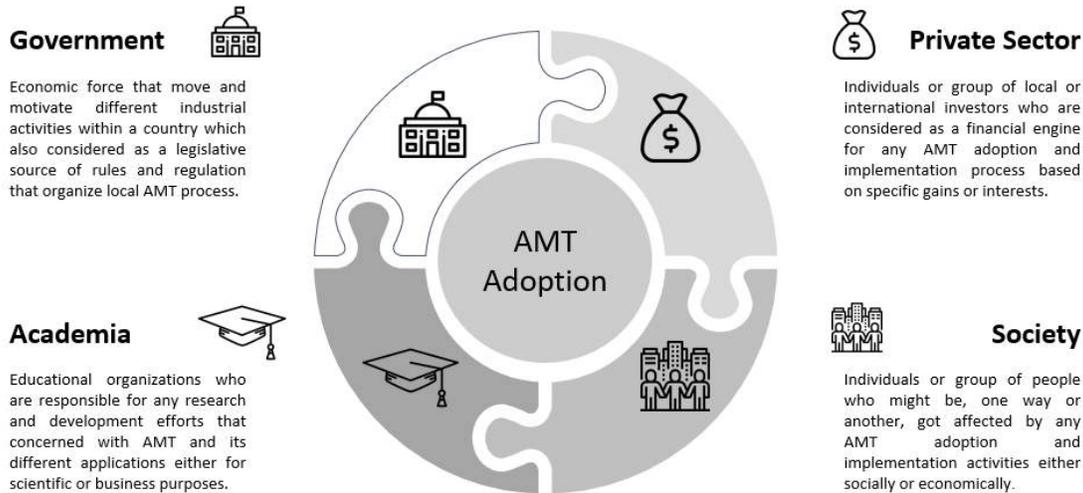
**Table 2: Eligibility criteria**

Inclusion	Exclusion
<ul style="list-style-type: none"> <li>• English language</li> <li>• Peer-reviewed papers, book chapters, official governmental reports, thesis and dissertations.</li> <li>• Cover one or more of the previously mentioned dimensions.</li> <li>• From 1985 until now.</li> </ul>	<ul style="list-style-type: none"> <li>• Other languages</li> <li>• Conference papers</li> <li>• Cover aspect other than the eight dimensions.</li> <li>• Earlier than 1985</li> </ul>

Moreover, about %61 of the studies contained in the literature review used questionnaires and structural equation modelling as a methodology. Other studies used other quantitative and qualitative methodologies, such as interviews and case studies. Based on that, it is possible to say that questionnaires and structural equation modelling considered as an appropriate type of methodology used in studies concerning AMT adoption.

By conducting a systematic literature review on the previous studies, it becomes evident that the main stakeholders of AMT adoption in most economies are; Government, Private Sectors, Academia, and Society. Understanding the interactions between the stakeholders will undoubtedly pave the road for successful AMT adoption in different types of industry (Löfsten and Lindelöf 2002). The following figure highlight the stakeholders of AMT adoption.

### Stakeholders of AMT Adoption



**Figure 1: Stakeholders of AMT adoption**

Eight different dimensions of the AMT implementation were used to group and categorize the critical factors that have an impact on the adoption of the AMT. These factors can be considered as both opportunities and challenges to the adoption and implementation process. If the firm gets benefits from these factors to adopt and implement AMT, then, those factors can be described as drivers; otherwise, they will be considered as barriers. The following table shows the different dimensions and each critical factor related to them.

**Table 3: Dimensions and critical factors that impact AMT adoption**

<b>Dimension</b>	<b>Critical Factor</b>	<b>Articles</b>
Planning	Long term strategy Consistency	(Chen and Small 1994), (Chen and Small 1996), (Efstathiades, Tassou et al. 2002), (Millen and Sohal 1998), (Small 2007), and (Sohal 1997)
Management	Support and motivation Management commitment Flexibility Research & development Information systems	(Beatty 1992), (Hottenstein and Dean Jr 1992), (Hynek, Janeček et al. 2009), (Zammuto and O'Connor 1992), (Gupta, Chen et al. 1997), (Beaumont, Schroder et al. 2002), (Leonard-Barton and Deschamps 1988), (Io Storto 2018), (McDermott and Stock 1999), and (Pao-Long and Lung 2002)
Business	Investment Cost Marketing Business capabilities Capital availability	(Khan and Nasser 2016), (El-Tamimi 2010), (Chan, Chan et al. 2001), (Putterill, Maguire et al. 1996), (Tesar 1995), and (Löfsten and Lindelöf 2002)
Technical	Technical capability Manufacturing capabilities Training Expertise Quality	(Kumar, Singh et al. 2018), (Bessant 1985), (Singh and Khamba 2009), (Udo and Ehie 1996), (Chang and Wang 2009), and (Singh and Khamba 2010)
Economy	Resources Ecosystem Infrastructure Government support	(Agyemang, Kusi-Sarpong et al. 2019), (Lyu and Gunasekaran 1993), (Zhao and Co 1997), (Eid 2009), (Sharma, Dangayach et al. 2008), and (du Preez and De Beer 2015)
Policy	Laws and Regulations Governmental agencies support	(Small and Yasin 1997), (Park 2000), and (Löfsten and Lindelöf 2002)
Society	Qualified HR Adequate training Relationship Communication Supplier Support Resistance	(Chung 1996), (Co, Eddy Patuwo et al. 1998), (Majchrzak 1988), (Siegel, Waldman et al. 1997), (Abd Rahman and Bennett 2009), and (Shani, Grant et al. 1992)
Environment	Environmental awareness	(Szalavetz 2017)

It would be possible to develop an algorithm using previously mentioned critical factors, which can be used to identify different drivers and barriers. For that purpose, a questionnaire can be constructed to measure the responses of the stakeholders toward the critical factors. Furthermore, analyzing these responses can be used to categories each vital element to be either a driver or a barrier. The following figure shows the drivers and barriers algorithm.

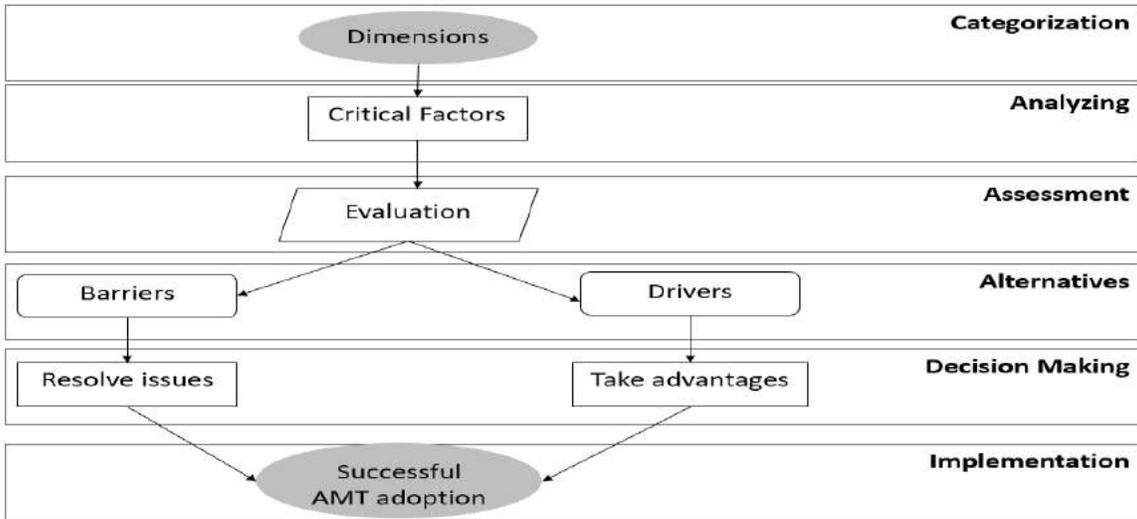
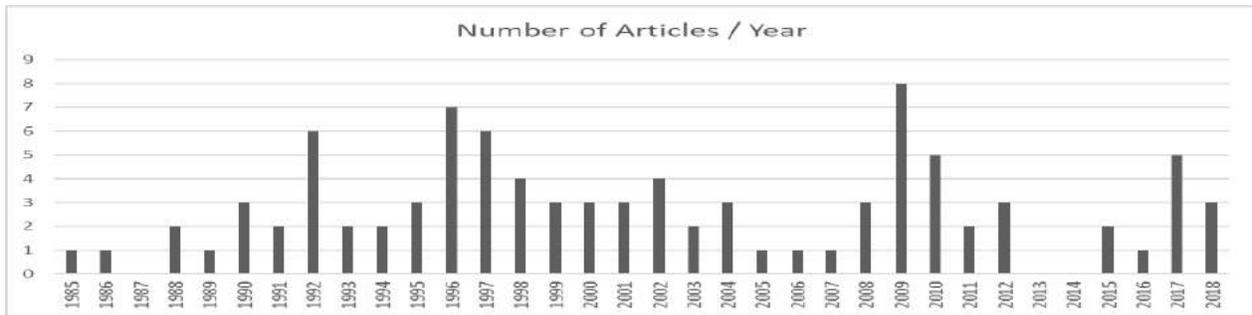


Figure 2: Drivers and barriers algorithm

## 4. RESULTS AND DISCUSSION

### 4.1. Articles Timeframe And Categories

This systematic literature review analyzed a total of 93 articles that were published from 1985 to 2018 and are non-uniformly distributed in time, as shown in the following graph.



Graph 1: Temporal distribution of articles selected for the literature review

It is noticeable that the last eight years have a smaller number of articles compared to other previous periods. The number of articles at a specific time might vary according to different circumstances, such as the dominant manufacturing technology of each period. In order to come up with a specific description for the published articles, the dimensional grouping of the articles was used to determine which type of articles were published each year.

**Table 4: Temporal distribution of categorizing articles selected for the literature review**

Year	Management	Planning	Technical	Business	Economy	Social	Policy	Environment	Mix	Total
1985			1							1
1986		1								1
1987										0
1988	1					1				2
1989						1				1
1990		1				1			1	3
1991	1			1						2
1992	3	2				1				6
1993	1				1					2
1994	1	1								2
1995		1		1					1	3
1996		1	1	1	1	2			1	7
1997	1	2			1	1	1			6
1998	1	1				2				4
1999	3									3
2000	1		1				1			3
2001	1			2						3
2002	3	1								4
2003	1	1								2
2004	1			1		1				3
2005					1					1
2006		1								1
2007	1									1
2008		1	1		1					3
2009		1	2	3	1				1	8
2010	1	1	2	1						5
2011	2									2
2012	1					1			1	3
2013										0
2014										0
2015	1				1					2
2016				1						1
2017	2				2			1		5
2018		1			1				1	3
Total	27	17	8	11	10	11	2	1	6	93
Percentage	29%	18%	9%	12%	11%	12%	2%	1%	6%	

It is noticeable that the management category has the most significant number of published articles around the timeline. On the other hand, there is only one article in the environment category. More details about the number of articles in each category are described in the table below.

**Table 5: Number of articles per category**

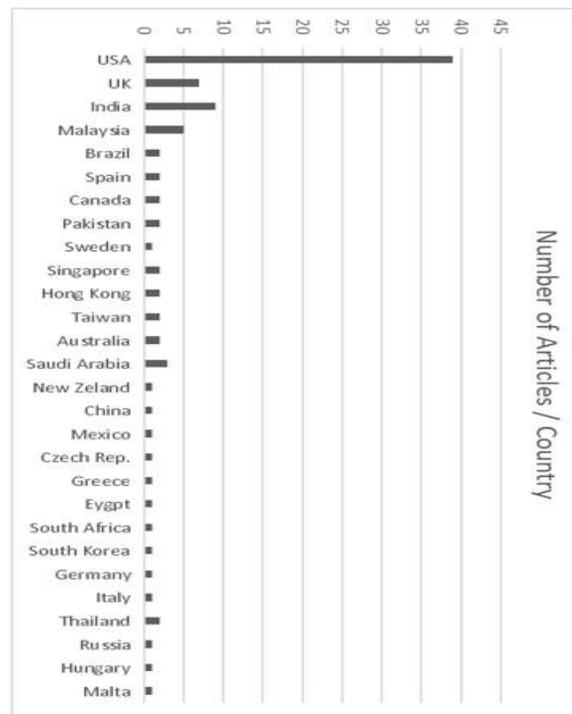
Category	Number of studies	Percentage
Management	27	29%
Planning	17	18%
Technical	8	9%
Business	11	12%
Economy	10	11%
Social	11	12%
Policy	2	2%
Environment	1	1%
Mix	6	6%
Total	93	

## 4.2. Demography

The articles in this study were selected to cover the majority of countries around the world. Categorizing articles based on demography would give a clearer idea about how different countries are interacting with AMT adoption and implementation. Each study was assigned to a country based on the place where the study was conducted. Almost all articles were categorized into countries except one article that didn't use a quantitative methodology or conduct any study but was used as a literature review for other articles. The following table and graph show the demography categorization of the studies.

**Table 6 and Graph 2: Number of Studies per Country**

Country	Number of articles
USA	39
UK	7
India	9
Malaysia	5
Brazil	2
Spain	2
Canada	2
Pakistan	2
Sweden	1
Singapore	2
Hong Kong	2
Taiwan	2
Australia	2
Saudi Arabia	3
New Zealand	1
China	1
Mexico	1
Czech Rep.	1
Greece	1
Egypt	1
South Africa	1
South Korea	1
Germany	1
Italy	1
Thailand	2
Russia	1
Hungary	1
Malta	1



From the above representations of the article's demography, it is obvious that the United States has the largest numbers of published articles by 39 articles followed by India which has nine articles. This can be an indication of the critical role of educational and research institutes in the amount and the quality of articles published in these United States. Also, the massive number of companies that are concerned with AMT in the Country. Furthermore, when comparing the number of articles between developed and developing countries, it is clear that developed countries have far more published articles than in developing countries. The percentage of published articles in developed countries is almost 67% while developing countries have 32% of the articles included in this literature review.

## 5. RESEARCHES GAPS AND FUTURE WORK

The critical gap in most of these articles is represented by the lack of making the necessary integrations between different critical factors that might have an impact on AMT adoption. To deeply understand the drivers and barriers of AMT adoption, it is important to have control over the critical factors from different dimensions. The previously mentioned dimensions such as planning, management, business etc..., can provide a broader view to understand how the adoption process works. Moreover, the integrations and interactions between the critical factors within the different dimensions should be deeply investigated and

studied. However any future work should highlight the interaction between the critical factors from the eight different dimensions. The integrations of the different critical factors can assure a successful adoption of the AMT. In the same time, the future efforts should focus on the new scientific approaches such as Industry 4.0, machine learning and internet of things in order to get benefits of these approaches in the AMT adoption and implementation.

## 6. CONCLUSION

To conclude, it is possible to say that the adoption process of the AMT is somehow complicated than what firms or governments might think. The sensitive nature of the AMT implementation makes it somehow risky to deal with. For that purpose, it is necessary to determine any critical factors associated with the adoption of the AMT and highly control these factors to come up with successful AMT implementation practices. Highlighting the AMT critical factors from different dimensions would provide decision-makers with a broader view of any issue that might get into the way of successful implementations for the AMT.

Categorizing adoption critical factors into different dimension can also help in following the root cause of any problem that might face the AMT implementation and eliminate them at early stages. Also, considering those critical factors before the adoption can be very helpful in uncovering any uncertainties associated with the implementation process. Moreover, using previous studies to conduct a systematic literature review is considered to be an effective approach to determine the critical factors of AMT adoption. However, conducting a quantitative research methodology such as questionnaires would be ideal to discover how these different factors are interacting with each other.

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## Effects of Verbal Versus Graphical Weather Information on a Pilot's Decision-making during Preflight

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**Abstract:** This study focused on the older technology of a verbal preflight weather briefing compared with the newer and emerging technology of digital textual and graphical weather pertinent to the flight route the pilot has chosen. The target population for this study was aviation students and instructors at Part 61 and 141 flight schools across the country. The accessible population for this study was flight students at a Florida university that had at least a private pilot's license through being employed as flight instructors. The 36 participants were selected from the accessible population based upon their availability and willingness to participate in the study. Institutional Review Board (IRB) approval was obtained from the university before conducting trials with human subjects.

Two weather scenarios were selected for the trials. Participants were assigned to one of four groups based on the order of the two formats, verbal or visual (graphical/textual), for the two different scenarios. Four open-ended questions for the two weather scenarios were given to participants, which resulted in a total of eight open-ended questions per participant. The open-ended questions designed and included in the instrument captured the "why" behind pilots' decision to "go" or "no-go." The qualitative analysis software, Nvivo®, was used to analyze the four open-ended questions for each of the two weather scenarios. To visualize this data, a diagram was formed. The study results, discussion, and future research are presented in the paper.

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### 1. INTRODUCTION

The purpose of this study was to determine if a pilot's likelihood to make a "go" or "no-go" decision during preflight is affected by the same weather information delivered in either a "verbal" or "visual (graphical/textual)" format. This study examined a pilot's confidence in his or her decision and risk perception based upon the weather that is presented in two different scenarios. The goal of this study was to make recommendations to Part 61, 91, and 141 pilots to determine which method for receiving preflight weather is more suitable for their learning style and ability to perceive risks.

Deteriorating weather conditions have been a threat to general aviation pilots for many years. Adverse metrological conditions have contributed to 35% of general aviation accidents, with 60% of these accidents occurring in instrument metrological conditions (Fultz & Ashley, 2016). Before conducting a flight, a pilot is legally responsible for being aware of weather conditions at his or her origin, destination, and flight route between both airports. All pilots have varying levels of risk perception and assessment, depending on their experience and level of aviation certification. Pilots also differ from one another with different learning styles that are best matched with presentations of the same weather information.

Traditionally, pilots have obtained a preflight weather briefing via a telephone call. This phone call allows pilots to receive all pertinent weather information verbally. The pilot is also able to receive a preflight advisory from the weather briefer, suggesting that the flight should be terminated based upon the outlook of adverse weather along the intended flight route. This advisory is included in your briefing by the briefer

stating, “visual flight rules (VFR) is not recommended,” which is triggered by current or forecasted weather conditions falling outside of the set parameters for the duration of the flight.

With the advancement of technology, pilots are now able to obtain preflight weather information textually and graphically over a computer, tablet, or smartphone. This newer method over the option of a verbal format cuts out the addition of the flight service station (FSS) providing a recommendation to the pilot to terminate his or her flight if hazardous weather is detected. Based on the learning style and experience level of the pilot, the different delivery methods for a preflight weather briefing may influence the likelihood of a “go” or “no-go” decision being made.

## **2.BACKGROUND INFORMATION**

### **2.1. Aviation Weather Briefings**

General aviation pilots operate under Part 91 of the Federal Aviation Regulations under Title 14 of the Code of Federal Regulations. Part 91.103 titled *Preflight action*, and subsection (a) describes what a pilot must obtain before conducting a flight. “Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight. For a flight under instrument flight rules (IFR) or a flight not in the vicinity of an airport, weather reports, and forecasts...” (FAA, 2017, 91.103a). These regulations do not define the sources of weather information that the pilot must use to obtain a preflight weather briefing; they only state that the pilot must be aware of all the weather concerning his or her flight.

The FAA only provides pilots with information related to weather products that are distributed by the National Weather Service and state that pilots need to exercise caution when using unfamiliar weather products and to consult an FSS (FAA, 2016). It further describes that as new weather products are developed, older textual and graphical products are phased out, leading to confusion between regulatory requirements and the new products. The FAA addresses this issue by stating all flight-related aviation weather decisions should be based on all available pertinent weather because every flight is unique, and multiple products may be necessary to meet weather regulatory requirements.

### **2.2. Theories Related To Analyzing Preflight Weather**

The FAA (2009) devotes a lot of attention to educating pilots on the different forms of decision-making, also known as aeronautical decision making (ADM). ADM is defined as the ability to take a structured and systematic approach to analyze changes that occur during flight and how these changes could affect the safe outcome of the flight. Using ADM properly requires good judgment, something which the FAA states can be taught through instruction and is not always exclusively a byproduct of experience. To capture decision-making in this study, specific Likert-type scale and open-ended questions that focused on both a final decision reached by a pilot after analyzing a preflight weather briefing and how confident they were in their decision were included in the final instrument.

One form of ADM that most closely relates to the analysis of a preflight weather briefing is analytical ADM (FAA, 2009). This follows the DECIDE model, which has pilots detecting a change or hazard, estimating the need to counter this change, choose a desirable outcome, identify actions that can successfully control change, do the necessary action, and evaluate the effect of the action. Analyzing all parts of a preflight weather briefing encompasses the DECIDE model as pilots already have a desired outcome for their flight and must weigh the changes detected in the weather briefing against this safe outcome.

Risk management is a second theory that is relevant to pilots analyzing preflight weather briefings. The FAA (2009) developed a risk assessment matrix that breaks down risk management into two functional processes: the analysis of risk likelihood and risk severity. Risk likelihood was rated from improbable to remote, occasional, and probable. Risk severity was rated from negligible, marginal, critical, and catastrophic. Pilots must consider all risks and their respective likelihood and severity, especially if the risk falls into the “high likelihood” and “high severity” region of the assessment matrix. Assessing risks

associated with weather is unique in that pilots can be provided with approved analyses, observations, and forecasts that describe the severity of hazardous weather. Weather forecasts, in particular, also give the pilot the ability to analyze both risk severity and risk likelihood. Pilots utilizing a weather briefer can also receive a dynamic analysis of their preflight weather when working with another human being who is disseminating the weather information relevant to the particular flight. To capture the pilot's perception of risks during a preflight weather briefing, there was a Likert-type scale question for each scenario that asked participants to rank the severity of perceived risks. This was also captured via two open-ended questions after each scenario that asked participants to describe the perceived risks and how these impacted their decision to "go" or "no-go."

### 3. METHODS

#### 3.1. Target Population And Sample

The target population for this study was aviation students and instructors at Part 61 and 141 flight schools across the country. The main reason students and instructors at flight schools were the target population are because this was the level of experience and certification directly related to this research. The accessible population for this study was flight students at one university. These students all held at least a private pilot's license up through certified flight instructors. These potential participants were located on or near the college campus that was easily accessible logistically to participants. Participants were required to have held at least a private pilot's license to establish that they had initial training on obtaining and analyzing a preflight weather briefing. The design of this study was chosen to compare varying weather conditions with the verbal and graphical/textual delivery of the preflight briefing. Each of the 36 participants was shown two weather briefings, one in a graphical format and one in a verbal format.

#### 3.2. Qualitative Data Analysis

Each survey contained four open-ended questions for both of the two weather scenarios, which resulted in a total of eight open-ended questions per participant. The four questions captured how the pilots reached the decision to "go" or "no-go," perceived risks after reading the weather briefing, how these risks affected their decision, and the reasons for the levels of confidence listed for each scenario. A categorical analysis method was used to find commonalities or differences between the verbal and visual formats for the weather briefings and any answer to an open-ended question that stood out or directly tied into a hypothesis from this study.

The qualitative analysis software, Nvivo®, was used to analyze the four open-ended questions for each of the two weather scenarios. The open-ended responses from the 36 participants were compiled into two documents: verbal and visual formats. A categorical analysis process was then performed by identifying common answers or themes among the 36 participants. To visualize this data, a comparison diagram was formed. These diagrams show the same open-ended question asked in both scenarios. The bubbles at the center of the diagram represent the format of weather briefing presented: either verbal or visual. These bubbles are linked to the open-ended question that was asked (the same question repeated twice for the two weather scenarios). Each bubble that branches off the open-ended question bubbles are the categories of common answers found when analyzing the open-ended responses. The numbers at the center of the bubbles show the number of responses by participants per category for a particular question. The "child" label on each arrow linking the bubbles together represents the software identifying the flow from the weather briefing format, to the open-ended question, and then to the category as a parent-child relationship. The numbers reflected are more than 36 because participants could respond with as many applicable answers as desired. Figure 1 below provides an example of the matrix provided by Nvivo.

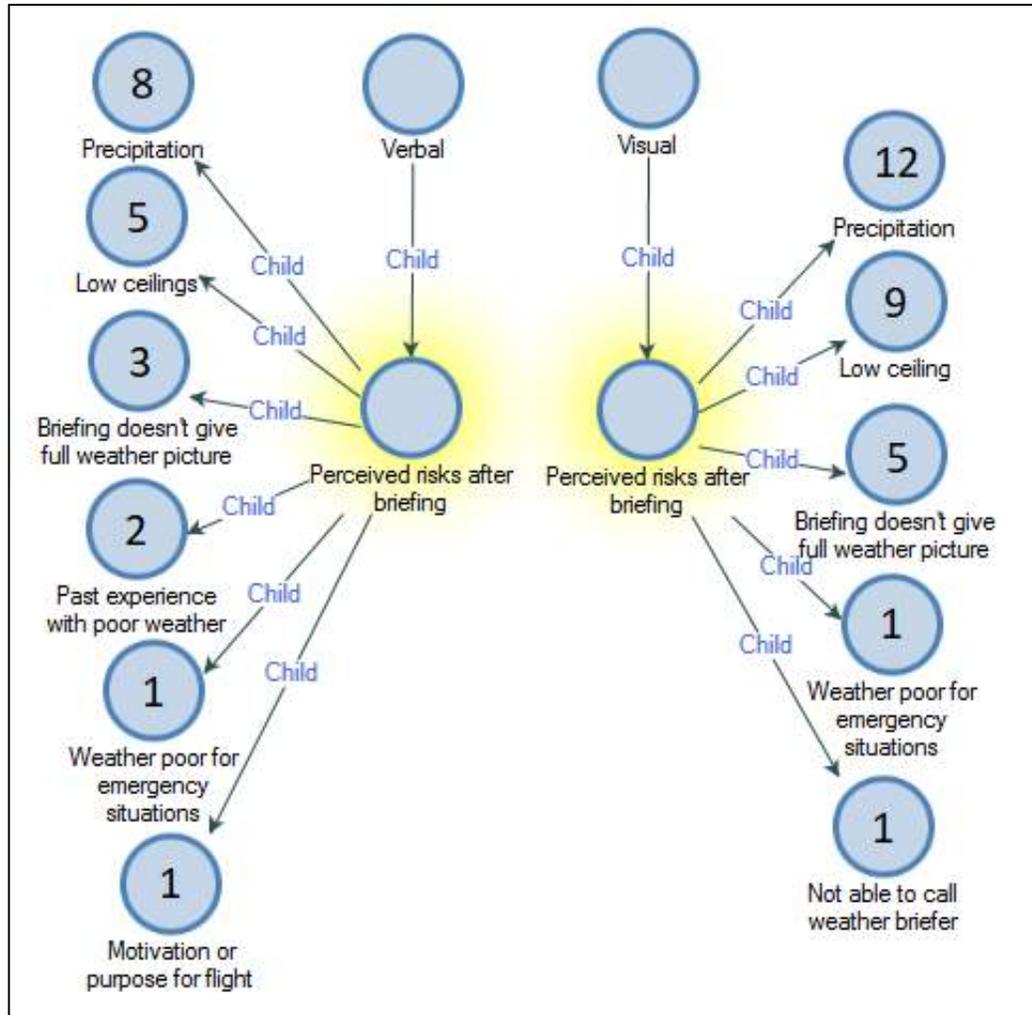


Figure 1 Perceived risks after receiving a weather briefing

## 4. RESULTS

### 4.1. Weather Briefing Format Comparison

The first open-ended question asked to each participant in both the verbal and visual formats for each weather briefing scenario was how the pilot rated the likelihood to either “go” or “no-go” on a VFR flight to the specified airport. This question generated many different types of answers and had the highest number of categories compared to the proceeding three questions. As seen in Figure 1, the most popular response for the verbal scenario was that 20 of the 36 pilots cited low cloud ceilings as the factor that contributed the most to their decision. This was followed by seven of the 36 pilots citing precipitation as the second highest factor when indicating how likely they were to proceed with their flight. These responses were also the highest reported factors for the visual scenario, with eleven of the 36 pilots indicating low ceilings and fourteen of the 36 pilots indicating that precipitation was a contributor to their likelihood to “go” or “no-go.”

It is interesting to point out that 20 out of 36 pilots cited low ceilings as a contributor to their likelihood to decide to “go” or “no go” in the verbal scenario. In comparison, only 11 did the same in the visual scenario. Likewise, 14 out of 36 pilots cited precipitation as a contributor to their likelihood to make a decision in the visual scenario. In comparison, only seven of the 36 pilots did the same in the verbal

scenario. There were six of the 36 pilots in the visual scenario and two of the 36 pilots in the verbal scenario that identified a lack of weather information in their briefing, and this contributed to their decision to “go” or “no-go.” Contributors to decision-making that were only mentioned for the verbal briefing included not being comfortable with a solo flight and that the weather conditions in the briefing were poor for a possible emergency situation. Each of these was reported by one out of 36 pilots. Likewise, asking for ATC assistance (reported by one out of 36 pilots), not being able to call a weather briefer (reported by one out of 36 pilots), and the usage of the visual radar (reported by 5 out of 36 pilots) were unique to the visual briefing format and were each listed by one out of 36 pilots.

For the verbal weather briefing, five of the 36 pilots said that the type of flight they were conducting played a role in proceeding with or canceling their flight. The type of flight depends on whether VFR or IFR is being followed or the fact that a training flight was being used in each scenario. In the visual briefing, five of the 36 pilots identified using the image of the radar, which shows the location and intensity of precipitation, as a contributor to their decision-making. The lack of aviation experience or a higher pilot certification was listed by four pilots for the verbal weather briefing and one pilot for the verbal briefing as a contributor to their final decision.

#### **4.2. Perceived Risk**

The second open-ended question asked to participants regarding the two scenarios was to identify risks that they perceived after analyzing each weather briefing. The risk reported the most was precipitation, with eight of the 36 pilots identifying this in the verbal scenario and twelve of the 36 pilots identifying this in the visual scenario. Low ceilings were the next-highest reported risk in each briefing, with five of the 36 pilots reporting it in the verbal briefing and nine of the 36 pilots reporting it in the visual briefing. A third common perceived risk between the two formats was that the briefing does not provide a full picture of the weather, with three of the 36 pilots and five of the 36 pilots reporting this in the verbal and visual briefing, respectively. The remaining risks perceived in each briefing had two or fewer pilots report them. For the verbal briefing, two of the 36 pilots identified past experience with poor weather as a risk, while the motivation or purpose for flying and the weather conditions being poor for emergency situations being reported each by one pilot. In the visual briefing, the same pilot, as in *Question 1*, listed the inability to call a weather briefer as a perceived risk. Just as in the verbal weather briefing, a pilot identified the reported weather in the visual scenario as being poor for a possible inflight emergency.

#### **4.3. Perceived Risk On Decision Making**

The third question pilots were asked regarding both weather scenarios were how the risks they perceived affected their decision to “go” or “no-go.” For a third time, low ceilings and precipitation were reported in both formats. Seven of the 36 pilots reported low ceilings, and one pilot reported precipitation as risks that impacted their decision-making for the verbal weather briefing. In the visual briefing, five of the 36 pilots reported low ceilings, while three of the 36 pilots reported low ceilings as risks that affected their decision.

The motivation or purpose of the flight was the highest-reported risk that affected a pilot’s final decision between both formats, with seven of the 36 pilots reporting this in the verbal briefing and six of the 36 pilots reporting it in the visual briefing. A few participants indicated that the weather scenarios did not provide a full picture of the weather for the route they were flying, with three of the 36 pilots indicating this in the verbal briefing and two of the 36 pilots indicating this in the visual briefing. When it came to a lack of aviation experience or holding a higher pilot certificate, four of the 36 pilots reported this as a risk that affected their decision to fly in the verbal briefing. In contrast, only one pilot reported this in the visual briefing.

Past experiences with poor weather were reported by four of the 36 pilots in the verbal briefing, with two of the 36 pilots reporting the same for the visual briefing. The last commonly reported risk that affected decision-making between both scenarios was the weather that was too poor for an inflight emergency, one pilot reported this in the verbal briefing, and two of the 36 pilots reported this for the visual briefing. There

were responses that were unique to the visual briefing that did not fit into any of the existing categories. The first was that one pilot reported a lack of equipment inside of the aircraft that could provide inflight weather information. The second unique response, also reported by only one pilot, was that the weather in the scenario was deemed specifically “not hazardous,” and therefore, the entirety of the information in the briefing was not a risk that affected decision-making.

#### **4.4. Confidence In Decision**

The fourth and final open-ended question asked to all participants twice, once per scenario, was to provide an explanation for the level of confidence that they expressed through answering the Likert-type scale question. Past experiences with poor weather were the most common answer for the verbal scenario reported by eight of the 36 pilot responses. In contrast, six of the 36 pilots reported the same in the visual scenario. The next highest-reported reason for each participant’s level of confidence was the motivation or purpose for their flight reported by six of the 36 participants in the verbal briefing and four of the 36 pilots in the visual briefing. Three of the 36 pilots in the verbal scenario answered that the briefing does not provide a full picture of the weather for the flight. In contrast, five of the 36 pilot participants answered the same for the visual scenario. The last common reason for the level of confidence between participants from both scenarios was the lack of aviation experience or pilot certification. This was reported by two of the 36 pilot participants in the verbal scenario and by four of the 36 pilot participants in the visual scenario.

Categories that were unique to the verbal scenario were low cloud ceilings (reported by five of the 36 pilot participants), and the weather is too poor to handle a possible inflight emergency (reported by one pilot participant). There were also two categories of answers in the visual briefing regarding the participants’ level of confidence in their decision to “go” or “no-go.” The first was that the combined data between the image of the radar and the graphical/textual weather data matched each other, which was reported by eight of the 36 pilot participants. The second category was only answered by one participant; this pilot felt uncomfortable calling and receiving weather information from a briefer that they did not personally know.

## **5. DISCUSSION**

The data from the open-ended questions suggest that the order in which a pilot receives a verbal and visual (graphical/textual) weather briefing does have an influence on their decision-making and confidence. This study provided each participant with two flight scenarios in different order. Both destinations were VFR training flights to an airport in Central Florida with similar weather between both scenarios. This simulated a pilot flying multiple legs, beginning at the origin airport and flying to either Sebring or Okeechobee, and then proceeding to the final destination. Multi-leg flights within the same region of one state are very common to general aviation training flights, which is directly relatable to the accessible population used in this study. The data suggests that the order in which a pilot receives different formats of weather briefings, dependent upon the type of weather at their destination, affects the likelihood to make a decision as well as the confidence in this decision. If a pilot is receiving a weather briefing for the first leg, the type of weather should determine which format of briefing should be used. Upon reaching this destination, if the pilot decides to continue with the flight, the pilot will then receive another briefing for the second leg. If the weather conditions have changed since receiving the first briefing, the pilot should consider which format of briefing to use due to the prior exposure to the initial weather and briefing from the first leg.

Another important factor to consider is the availability of equipment at various airports from leg to leg. An airport that has technology such as computers or tablets available for use will allow pilots to obtain visual weather briefings. However, depending on the size, location, and type of clientele, a smaller airport may only have telephones available, making a verbal briefing the only format available to visiting pilots. In this case, this study suggests that pilots should be aware of the preflight briefing equipment available at the various airports along their intended route of flight. If changing weather is to be encountered during the

various legs, and pilots are forced into choosing one format over another due to equipment limitations, decision and confidence could be affected.

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## Universidad Autónoma de Santo Domingo Energy Forecast

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**Abstract:** Energy time series data for Universidad Autonoma de Santo Domingo is analyzed and forecast by the moving window spectral method to capture cyclical components and effects. The historical record is 217 months from March 2001 to March 2019. A model is fitted to 205 historical observations from March 2001 to March 2018. The forecast period is 12 months from April 2018 to March 2019. The two overlapping 12 actual and forecast months are compared.

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### 1. INTRODUCTION

Forecasting energy consumption has been a subject of interest in many countries. Azadeh et al. (2008) conducted monthly energy forecasting in Iran. In Thailand, Panklib, et al. (2015) used a neural network model to compare performance with a multiple linear regression method. In Italy, Bianco et al., (2013) proposed multiple linear regression to predict the energy consumption with GDP and population as independent variables. Guo et al., (2018) tested the applicability of a new monthly electricity forecasting framework to predict energy consumption in china. The framework is based on a method of vector error correction and self-adaptive screening. The main benefit of this proposal is to address the problem of data types and data length by identifying the most influential input factor groups for the model.

Energy time series data for Universidad Autónoma de Santo Domingo (UASD) is analyzed and forecast by the moving window spectral method (mws) (Ngnepieba and Ridley, 2007; Ridley and Womer, 1981; Ridley, 1994, 2001, 2003; Ridley and Llaugel, 2000; Ridley and Ngnepieba, 2009) to capture cyclical components and effects. Data analysis and forecasting in the time domain is natural but it ignores the fact that time series may be made up of trend and cyclical components, and the components might be varying, growing and shrinking in different ways. The mws method divides the history into overlapping windows of length equal to the longest dominant cycle in the data.

Although the analyst is free to try different window lengths and thereby estimate and choose it empirically, these data are expected to contain at least a seasonal effect represented by a 12-month cycle. In that case the window length must be a whole multiple of 12. The mws method uses a fast Fourier transform (FFT) to decompose each window into cyclical components. Whereas the original data are represented in the time domain where they are indexed by time, the component cycles are represented in the complex frequency domain where they are indexed by frequency.

These components are assumed to be a set of correlated sequences. A complex function is fitted, separately by frequency, to each sequence of components by simple regression. Each component sequence is then extrapolated from the most recent sequence to the following sequence of values. The extrapolated sequences are then inverse transformed back to the time domain where they are interpreted in the normal way by the human observer. The historical record is 217 months from March 2001 to March 2019. A model is fitted to 205 historical observations from March 2001 to March 2018. The forecast period is 12 months from April 2018 to March 2019. The two overlapping 12 actual and forecast months are compared.

### **1.1. The University**

In its main campus, UASD has 18 buildings that are important to energy consumption. During the period from September 2017 to September 2018, the average energy consumption throughout the campus was 1,389 MWh / month, with a maximum demand of 3.8 MW,

Twenty years ago, the University had fewer buildings. Many have been added over the years in accordance with economic possibilities. The most important buildings added are: The administrative tower, the high technology laboratories, and the central library. All of these have added greatly to the energy and power demand by the main campus.

One of the deficiencies of structural development in the Dominican Republic can be seen within UASD. New buildings are built without having been planned and because of that, the services that support the proper functioning of these are inadequate. Among these we can mention the electricity service. In order to provide electricity efficiently, the production must adapt to the demands of the current demand hour by hour. The lack of generating supply options, and flexibility, does not permit efficient scheduling.

Other deficiency factors are insufficient backup generating capacity in case of failure of a generator, and support elements such as underrated insulators and undersized conductors, etc. Under insulation can cause outages due to electrical faults. Undersized conductors cause excessive heat losses. Forecasting of power requirements are critical for the purpose of providing information to plan for future service requirement. In this paper we forecast energy consumption. The forecast energy consumption can be converted to power demand by dividing by the power factor which is known to be 0.9.

## **2. THE DATA**

The historical record of monthly energy consumption in kilowatt hours (kwh) from March 2001 to March 2019 for Universidad Autónoma de Santo Domingo (UASD) is given in table 1. The data include consumption at the main campus of the University. Preliminary analysis of the data indicates some trend and seasonal variations (see Figure 1).

**Table 1. University monthly energy consumption (in Kwh)**

Energy Consumption													
Date	KWh	Date	KWh	Date	KWh	Date	KWh	Date	KWh	Date	KWh	Date	KWh
Mar-01	426,369	Oct-03	537,600	May-06	50,880	Dec-08	772,800	Jul-11	967,200	Feb-14	908,229	Sep-16	1,488,000
Apr-01	548,400	Nov-03	516,000	Jun-06	741,600	Jan-09	717,600	Aug-11	816,000	Mar-14	1,435,200	Oct-16	1,636,800
May-01	418,800	Dec-03	415,200	Jul-06	753,600	Feb-09	998,400	Sep-11	1,137,600	Apr-14	1,598,400	Nov-16	1,483,200
Jun-01	472,800	Jan-04	235,200	Aug-06	748,800	Mar-09	1,036,800	Oct-11	1,137,600	May-14	1,497,600	Dec-16	1,555,200
Jul-01	428,400	Feb-04	439,200	Sep-06	1,003,200	Apr-09	1,130,400	Nov-11	1,135,200	Jun-14	1,411,200	Jan-17	940,800
Aug-01	231,600	Mar-04	573,600	Oct-06	1,171,200	May-09	1,094,400	Dec-11	784,800	Jul-14	1,478,400	Feb-17	974,400
Sep-01	29,520	Apr-04	626,400	Nov-06	1,255,200	Jun-09	1,154,400	Jan-12	703,200	Aug-14	1,550,400	Mar-17	1,257,600
Oct-01	501,600	May-04	518,400	Dec-06	1,060,800	Jul-09	1,180,800	Feb-12	1,005,600	Sep-14	1,502,400	Apr-17	1,512,000
Nov-01	554,400	Jun-04	446,400	Jan-07	792,000	Aug-09	1,183,200	Mar-12	1,118,400	Oct-14	1,728,000	May-17	1,320,000
Dec-01	429,600	Jul-04	532,800	Feb-07	772,800	Sep-09	1,344,000	Apr-12	1,087,200	Nov-14	1,848,000	Jun-17	1,502,400
Jan-02	232,800	Aug-04	628,800	Mar-07	962,400	Oct-09	1,358,400	May-12	921,600	Dec-14	1,593,600	Jul-17	1,392,000
Feb-02	412,800	Sep-04	696,000	Apr-07	1,197,600	Nov-09	1,214,400	Jun-12	1,171,200	Jan-15	1,012,800	Aug-17	1,464,000
Mar-02	470,400	Oct-04	662,400	May-07	1,070,400	Dec-09	914,400	Jul-12	1,200,000	Feb-15	1,060,800	Sep-17	1,344,000
Apr-02	516,000	Nov-04	712,800	Jun-07	1,058,400	Jan-10	696,000	Aug-12	993,600	Mar-15	430,400	Oct-17	1,387,200
May-02	516,000	Dec-04	460,800	Jul-07	1,089,600	Feb-10	1,113,600	Sep-12	162,000	Apr-15	1,593,600	Nov-17	1,680,000
Jun-02	429,600	Jan-05	314,400	Aug-07	1,058,400	Mar-10	1,221,600	Oct-12	1,454,400	May-15	1,579,200	Dec-17	1,248,000
Jul-02	494,400	Feb-05	525,600	Sep-07	1,118,400	Apr-10	1,183,200	Nov-12	460,800	Jun-15	1,689,600	Jan-18	936,000
Aug-02	460,800	Mar-05	664,800	Oct-07	1,224,000	May-10	1,048,800	Dec-12	1,161,600	Jul-15	1,718,400	Feb-18	1,152,000
Sep-02	535,200	Apr-05	511,200	Nov-07	1,142,400	Jun-10	996,000	Jan-13	878,400	Aug-15	1,713,600	Mar-18	1,305,600
Oct-02	468,000	May-05	403,200	Dec-07	691,200	Jul-10	952,800	Feb-13	1,358,400	Sep-15	1,598,400	Apr-18	1,516,800
Nov-02	614,400	Jun-05	410,400	Jan-08	784,800	Aug-10	988,800	Mar-13	1,392,000	Oct-15	1,545,600	May-18	1,521,600
Dec-02	487,200	Jul-05	420,000	Feb-08	1,000,800	Sep-10	1,161,600	Apr-13	1,454,400	Nov-15	244,800	Jun-18	1,406,400
Jan-03	201,600	Aug-05	408,000	Mar-08	950,400	Oct-10	1,272,000	May-13	1,627,200	Dec-15	1,339,200	Jul-18	1,348,800
Feb-03	456,000	Sep-05	460,800	Apr-08	1,135,200	Nov-10	1,041,600	Jun-13	1,449,600	Jan-16	1,276,800	Aug-18	1,531,200
Mar-03	518,400	Oct-05	597,600	May-08	986,400	Dec-10	727,200	Jul-13	1,531,200	Feb-16	1,171,200	Sep-18	1,430,400
Apr-03	513,600	Nov-05	811,200	Jun-08	1,051,200	Jan-11	542,400	Aug-13	1,473,600	Mar-16	1,483,200	Oct-18	1,051,200
May-03	482,400	Dec-05	883,200	Jul-08	1,111,200	Feb-11	880,800	Sep-13	1,785,600	Apr-16	1,497,600	Nov-18	1,576,800
Jun-03	482,400	Jan-06	46,320	Aug-08	96,480	Mar-11	487,200	Oct-13	1,641,600	May-16	1,622,400	Dec-18	1,670,400
Jul-03	446,400	Feb-06	429,600	Sep-08	1,058,400	Apr-11	1,017,600	Nov-13	1,550,400	Jun-16	1,444,800	Jan-19	936,000
Aug-03	302,400	Mar-06	600,000	Oct-08	1,190,400	May-11	1,075,200	Dec-13	1,065,600	Jul-16	1,555,200	Feb-19	1,123,200
Sep-03	494,400	Apr-06	720,000	Nov-08	996,000	Jun-11	955,200	Jan-14	955,200	Aug-16	1,502,400	Mar-19	1,404,000

The summary statistics of the data are as follows:

Minimum	29.520
Maximum	1848.000
Mean	976.401
Standard dev.	434.288
Mean abs dev.	367.446
Auto correl.	0.753
Coeff of var.	0.445
MAD/S.	0.846
ChiSqr (7, 5%)=14	39.653

The summary data for Table 1 shows the MAD/S = 0.846 and is a little higher than the value of 0.8 for a normal distribution. The ChiSqr test statistic of 39.653 is greater than the theoretical ChiSqr value of 14. It does appear that the data are normally distributed. Nevertheless, the histogram (not shown) is symmetrical. That will enable the construction of prediction when it comes time to forecast future values.

### 3. THE MWS MODEL

Consider a stationary time series model where UASD is represented by  $y$ :

$$y(t) = \sum_{k=1}^T y(t-k)b(k) + \varepsilon(t), t = T+1, T+2, T+3, \dots, \infty \quad (1)$$

where

$b(k)$  = system parameter, coefficient of  $y$  lagged  $k$  time periods,

$\varepsilon(t)$  = an unobservable error term, a sequence of independent identically distributed normal random variables with mean 0 and variance  $\sigma^2$ .

$T$  = window length.

The Cooley-Tukey (1965) complex FFT is used to estimate the spectral density for each window  $y(m-1+t)$ ,  $m = 1, 2, \dots, n-T+1$  from

$$Y_m(\omega) = \sum_{t=1}^T y(m-1+t) \exp(-i\omega t), \quad -\pi \leq \omega \leq \pi \quad (2a)$$

Where  $m$  is the window number and the index of the realization of a cycle at frequency  $\omega$  and  $i = \sqrt{-1}$ .

That is, there are  $n-T+1$  realization.

Likewise,

$$B(\omega) = \sum_{k=1}^T b(k) \exp(-i\omega k), \quad (2b)$$

the spectral density function of the impulse response function  $b(k)$ , is constant across windows, and

$$\varepsilon_m(\omega) = \sum_{t=1}^T \varepsilon(m-1+t) \exp(-i\omega t), \quad (2c)$$

the spectral density function of independent identically distributed time domain errors, is constant [Chatfield(1996, ch. 6)] across frequency.

### 4. THE MWS PARAMETERS

The MWS method generates two sets of parameter estimates, one in the frequency domain (Table 2) and one in the time domain (Table 3). All computations were made by a computer program [see Ridley (2002)]. Each line entry in Table 2 contains an estimate of the parameters  $|\hat{B}(\omega)|$  which is the coefficient in a first order autoregressive model. The standard error of estimate for the parameters is  $S$ . The number of data points after first differencing is  $205-1=204$ . The error degrees of freedom =  $n-T-1 = (204-12-1) = 191$ . The  $t$  statistic for a 5% level of significance is approximately 2. The first entry corresponds to the zero frequency, that is, the non-periodic trend component. The  $t$  test statistic  $1.004/0.00206 = 487.179$  exceeds 2, so this component is significant at the 5% level. The next component corresponds to the cycle that repeats once every 12 months. It has a period of 12 months. That component, as well as all other components are significantly different from zero.

Each coefficient has a magnitude close to 1. The coefficient of the zero-frequency trend is 1.004. The cycles have fractional coefficients implying that those cycles are falling in magnitude over time. The coefficient of the dominant 12-month cycle is 0.956. The coefficient of the 2-month cycle is very close to 0.904.

**Table 2. Frequency domain parameter estimate  $|\hat{B}(\omega)|$**

FREQUENCY No.	PERIOD	PARAMETER ESTIMATES magnitude/shift	S	t
0	----	1.004	0.00206	487.179
1	12.0	0.956	0.02109	45.345
2	6.0	0.939	0.02462	38.148
3	4.0	0.908	0.02991	30.359
4	3.0	0.836	0.03924	21.298
5	2.4	0.882	0.03380	26.091
6	2.0	0.904	0.03037	29.772

After inverse transformation back to the time domain, the model parameter estimates are given in Table 3 and equation 3. The parameters are those of a distributed lag function. This is also an impulse response function.

$$y(t) = 0.407y(t - 1) + 0.029y(t - 2) + 0.011y(t - 3) + \dots + 0.912y(t - 12) \quad (3)$$

**Table 3. Impulse response  $\hat{b}(t)$**

Lag	1	2	3	4	5	6	7	8	9	10	11	12
$\hat{b}(t)$	0.407	0.029	-0.011	0.005	0.003	-0.019	0.009	0.014	-0.006	-0.003	0.008	.912

### 5. FREQUENCY DOMAIN ANALYSIS OF VARIANCE

After the data are transformed to the frequency domain, a lagged model regression is performed on each component frequency. The results are shown in Table 4. The first row corresponds to the zero-frequency trend component. The column labelled density lists the spectral density distribution of the data. The trend component makes up 73.34 percent of the total spectrum. The total sum of squares (SST) of the variation about the mean of the data makes up 79.49 percent of that variation. The portion of SST that is error is represented by SSE and makes up 0.5494. The percentage that is explained by the MWS model  $R^2$  is 99.3%. The sum of squares explained by the model is  $79.49 - 0.5494 =$  approximately 78.9430 (due to various computational rounding errors). The number of degrees of freedom for the univariate model is 1. So, the mean square explained by the model (MSM) is  $78.9430/1 = 78.9430$ . The means square error =  $0.5494/192 = 0.002876$ . MSM and MSE are chi square distributed so the ratio  $MSM/MSE = 78.9430/0.002876 =$  approximately 27,444 is F distributed. Since the  $F = 27,444$  test statistic is greater than 6.93, we conclude that the model is a good fit to the data. This is also true for each frequency component. In passing, we note that SSE is approximately constant across all frequencies suggesting that the data are stationary [Chatfield(1996, ch. 6)].

**Table 4. Frequency domain Analysis of Variance**

Freq	Period	Density%	SST%	SSE%	$R^2$	MSM	MSE	F
0	-	73.34	79.49	0.5494	0.993	78.9430	0.002876	27444
1	12	6.15	6.16	0.5281	0.914	5.6300	0.002765	2036
2	6	5.83	4.35	0.5052	0.884	3.8475	0.002645	1455
3	4	4.49	3.01	0.5159	0.829	2.4961	0.002701	924
4	3	3.17	1.70	0.5005	0.705	1.1966	0.002621	457
5	2.4	3.59	2.35	0.5131	0.782	1.8389	0.002686	685
6	2	3.44	2.94	0.5186	0.823	2.4172	0.002715	890
Grand total		100.00	100.00					

Table explanation:

FREQ-frequency. Number of cycles per window of length 12

PERIOD-time to complete one cycle

DENSITY-Relative size of this component

SST-total sum of squares

SSE-sum of squared errors

$R^2$ -coefficient of determination

MSM-mean square explained by model (degrees of freedom = 1)

MSE-mean square unexplained by model (degrees of freedom =191)

F-(degrees of freedom in numerator = 1, denominator = 191,  $\alpha=1\%$ ) = 6.93

Number of historical data points = 205.

## 6. TIME DOMAIN ANALYSIS OF VARIANCE

After all estimates are inverse transformed to the time domain, the analysis of variance is repeated. The results are shown in Table 5. The percentage of the variations in the data that are explained by the model  $R^2$  is 38%. The Durban Watson static is expected to be biased so we use it sparingly. The value being less than the ideal of 2.0 suggests that there is some negative correlation in the data. The test statistic  $F = \text{MSM}/\text{MSE}$  ratio of 116.9 is greater than the theoretical value of 6.93. This suggests that the model is a good fit to the data and should have good predictive capability.

**Table 5. Time domain Analysis of Variance**

VARIABLE	SST	SSE	$R^2$	DW(192, 1)	MSM( 1)	MSE(191)	F( 1,191)
UASDE*	33588.50	20835.050	0.380	1.50	12753.45	109.084	116.9

\* - units are in ('000')

SST - total sum of squares

SSE - sum of squared errors

$R^2$  - coefficient of determination

DW - Durbin Watson statistic (number of windows, number of variables)

MSM - mean square explained by model (degrees of freedom)

MSE - mean square unexplained by model (degrees of freedom)

F - (degrees of freedom in numerator, denominator,  $\alpha = 1\%$ ) = 6.93

Number of historical data points = 205. Window length = 12

## 7. REVIEW OF THE MWS WINDOW LENGTH

Table 6 shows MSE(T) and  $R^2(T)$  for different values of window length. We recognize that in time series models the coefficient of determination ( $R^2$ ) may be a biased measure of the actual fit (Maddala, 1992). So, in this analysis  $R^2$  is used only as a measure of relative fit for each component of the model. Visual inspection of the data strongly suggested a periodicity of 12 months and therefore a window length of 12 months. As the window length departs from 12 months, MSE(t) rises sharply away from the optimal value of 109.084. A window length of 24 months will include two windows each of length 12 months. However, the number of windows is reduced. The result is MSE(T) = 127.089, higher than the optimal value. There seems little chance of omitting any significant frequencies by limiting the window length to 12.

**Table 6. MSE(t) and  $R^2$  (T) for different window lengths**

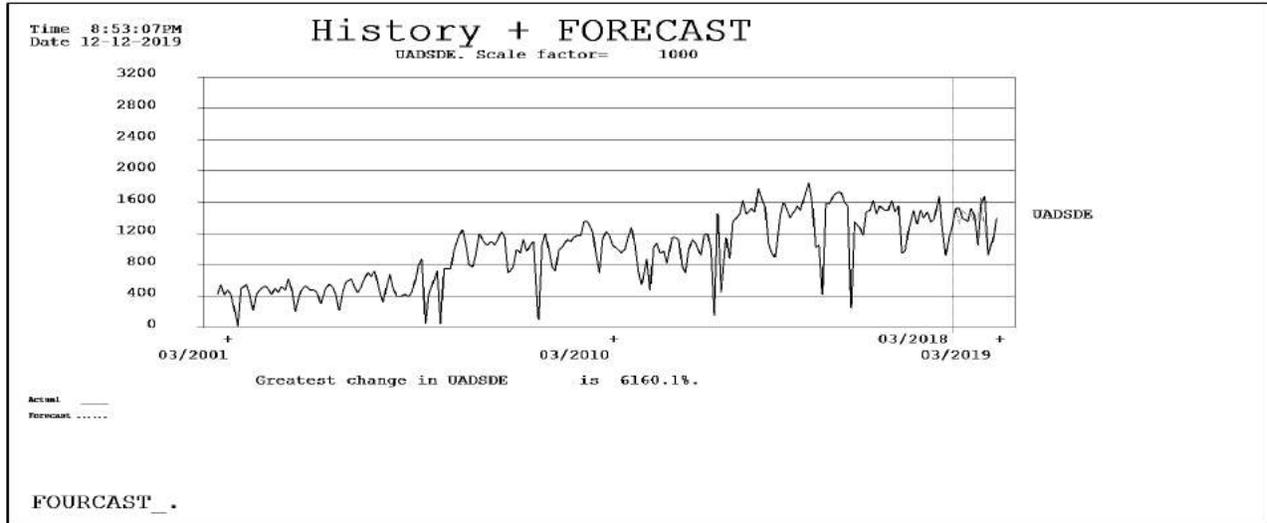
<b>WINDOW LENGTH</b>	<b>6</b>	<b>8</b>	<b>10</b>	<b>12</b>	<b>14</b>	<b>16</b>	<b>24</b>
MSE(T)	112.422	110.409	125.296	109.084	133.570	145.319	127.089
$R^2$ (T)	0.375	0.386	0.293	0.380	0.238	0.165	0.244

## 8. FORECAST

The forecast shown below (Table 7) shows the actual error, comparing forecast with real consumption data. The difference in the annual actual and forecast energy is 1.253%. This suggests that even when only an annual forecast is required it helps to make 12 monthly forecasts and add them. The mean absolute monthly forecast error is 9.254%. The table also shows the 50% prediction limits for the forecast, and in all cases, the actual consumption is between those limits. Figure 1 is the computer output from the forecasting software.

**Table 7. Actual vs. Estimated Energy Consumption**

<b>Date</b>	<b>FORECAST KWH</b>			<b>Actual</b>	<b>%Error</b>
	<b>Lower prediction limit</b>	<b>Estimated</b>	<b>Upper prediction limit</b>		
Apr-18	1276.733	1500.230	1723.727	1516.800	-1.092
May-18	1016.375	1332.648	1648.921	1521.600	-12.418
Jun-18	1112.409	1499.702	1886.995	1406.400	6.634
Jul-18	955.728	1403.024	1850.320	1348.800	4.020
Aug-18	959.888	1459.974	1960.060	1531.200	-4.652
Sep-18	800.074	1347.921	1895.768	1430.400	-5.766
Oct-18	802.437	1394.140	1985.844	1051.200	32.624
Nov-18	1027.386	1659.936	2292.486	1576.800	5.272
Dec-18	606.705	1277.760	1948.815	1670.400	-23.506
Jan-19	274.391	981.674	1688.956	936.000	4.880
Feb-19	411.971	1153.609	1895.247	1123.200	2.707
Mar-19	524.581	1299.107	2073.634	1404.000	-7.471
<b>Annual</b>	<b>9768.678</b>	<b>16309.73</b>	<b>22850.77</b>	<b>16516.8</b>	<b>1.253</b>
				<b>Average Annual %Error</b>	1.253
				<b>Mean Absolute Monthly %Error</b>	9.254



**Figure 1. Forecast of Energy Consumption (in Kwh)**

Figure 1 is a plot of the historical record of energy consumption for UASD for the period March 2001 to March 2019. It shows evidence of trend and seasonality. The forecasting model captures these components and uses them to develop the forecast for the 12-month period April 2018 to March 2019, as shown.

## 9. CONCLUDING REMARKS

The National Council of Energy of Dominican Republic requires that all public institutions control energy consumption and reduce waste. UASD is a public institution and must comply with that regulation. This includes maintaining a power factor of 0.90 to avoid penalties (SIE, 2007). Monitoring the energy use and controlling the power factor through a good forecast, we can better design the expansion and build new facilities.

Forecasting is essential for planning. In the short term, a forecast is needed to predict the needs for materials, products, services and other resources to respond to changes in demand. A Long-term energy forecast will allow us to make better selections of normal demand and emergency power plant equipment and systems.

The time series of monthly energy consumption for UASD was reviewed and found to be made up of trend, seasonal and multiple cyclical components. Therefore, it is imperative that model building and forecasting not be performed on the aggregate data for this time series. Instead, the data must first be decomposed into its components and each component forecast separately. That permits the components to evolve in different ways. We observed from inspection that the dominant cycle is twelve months. Therefore, the window length that was chosen to be appropriate was 12. Other possibilities are whole multiples of 12 equal to 24, 36,... Based on a 12 month window, a model was built for all but the last 12 months. The mean square error was found to be 109.084 kwh squared. To validate the choice of 12, the window length was varied from 6 to 24. The mean square error was lowest when the window length was 12.

Finally, the model was used to forecast the last 12 months and compare it with the last 12 actual months. The monthly forecast mean square absolute error is 9.254%. The annual forecast error is 1.253%. It is recommended that when an annual forecast is required, 12 monthly forecasts should be made and added. Because of the high accuracy, we conclude that the mws model and forecast are reliable methods for the university to use in analysis and planning for future electricity consumption and demand.

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