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Founded in 1971, the American Institute of Constructors mission is to promote individual professionalism and excellence throughout the related fields of construction. AIC supports the individual Constructor throughout their careers by helping to develop the skills, knowledge, professionalism and ethics that further the standing of the construction industry. AIC Members participate in developing, and commit to, the highest standards of practice in managing the projects and relationships that contribute to the successful completion of the construction process. In addition to membership, the AIC certifies individuals through the Constructor Certification Commission. The Associate Constructor (AC) and Certified Professional Constructor (CPC) are internationally recognized certifications in the construction industry. These two certifications give formal recognition of the education and experience that defines a Professional Constructor. For more information about the AIC please visit their website at www.professionalconstructor.org.

OUR MISSION

• To promote individual professionalism and excellence throughout the related fields of construction.

• A qualifying body to serve the individual in construction, the Constructor, who has achieved a recognized level of professional competence; 

• Opportunities for the individual constructor to participate in the process of developing quality standards of practice and to exchange ideas; 

• Leadership in establishing and maintaining high ethical standards; 

• Support for construction education and research; 

• Encouragement of equitable and professional relationships between the professional constructor and other entities in the construction process; and 

• An environment to enhance the overall standing of the construction profession.
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1971-74 Walter Nashert, Sr., FAIC
1975 Francis R. Dugan, FAIC
1976 William Lathrop, FAIC
1977 James A. Jackson, FAIC
1978 William M. Kuhne, FAIC
1979 E. Grant Hesser, FAIC
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1981 Robert D. Nabholz, FAIC
1982 Bruce C. Gilbert, FAIC
1983 Ralph. J. Hubert, FAIC
1984 Herbert L. McCaskill Jr., FAIC
1985 Albert L. Culberson, FAIC
1986 Richard H. Frantz, FAIC
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1989 T.R. Benning Jr., FAIC
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1991 David Wahl, FAIC
1992 Richard Kafonek, FAIC
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1996 Martin R. Griek, AIC
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2000 William R. Edwards, AIC
2001-02 James C. Redlinger, FAIC
2003-04 Stephen DeSalvo, FAIC
2005-06 David R. Mattson, FAIC
2007-09 Stephen P. Byrne, FAIC, CPC
2009-11 Mark E. Giorgi, FAIC
2011-12 Andrew Wasiniak, FAIC, CPC
2012-13 Tanya Matthews, FAIC, DBIA
2013-14 David Fleming, CPC, DBIA
2014-15 Paul Mattingly, CPC
2015-16 Joe Rietman, CPC
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ABSTRACT

This paper gives an overview of a study conducted in a geographical area of the US to understand the millennial generation’s perception of the workplace of the construction industry. Many organizations face the challenge of integrating diverse generations in a workplace. With the retirement of a large number of Boomers and the current intake of Millennials in the workplace, organizations are facing a challenge to attract and retain the millennial generation. Workplace expectations of the millennial generation and employees are compared with the expectations of the workplace amongst different generations in the construction industry.

Keywords: millennials, workforce, retention, generations

Authors

Dr. Christine Piper has completed research in the areas of WBE certification, attracting and retaining craft workers, schedule development, and continuing education programs for National Association of Women in Construction, Modular Building Institute and ITT Tech.

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INTRODUCTION

Among the many challenges in an organization, one of them is dealing with a diverse workforce. This diversity is not just limited to gender, religious, ethnic and racial backgrounds, but relates to the various generational values that are present in the workplace today. The current workforce in the construction industry comprises the greatest diversity of generations. There are four generations that are currently involved in the workplace. They are the Silent Generation, Baby Boomers, Generation X and Generation Y or the Millennials. The US Census Bureau in the year 2006 stated that the youngest generation entering the workforce numbered around 81 million, which is almost one-fourth of the total American population. With the retirement of a large number of US employees belonging to the Baby-Boomer generation, organizations face a crisis to recruit and retain the generations younger than the Baby Boomers who hold different values, attitudes and expectations from the workplace (Ng, Shweitzer, & Lyons, 2010). The Society for Human Resource Management (SHRM) study in the year 2004 conducted by Mary E. Burke, states that there are three areas where the generations differ: work ethics, managing change and perception of organizational hierarchy. Other researchers suggest that the management associates the millennials with common stereotypes that include disloyalty, entitlement, and casual and unmanageable (Thompson & Gregory, 2012). Based on the studies conducted by the above researchers, the following questions arise: What are the expectations of the millennial generation of the workplace? Are these expectations similar to the employees currently working in the construction industry? This research study will examine the workplace expectations of the millennial generation and the perception of the workplace by current employees and compare the expectations of the workplace amongst different generations in the construction industry.

LITERATURE REVIEW

The current construction industry consists of four generations working together with each other. The four groups are The Silent Generation, the Baby Boomers, Generation X and Generation Y also known as The Millennials. The Silent Generation includes those born between 1925 and 1945; Baby Boomers between 1946 and 1964; Generation X between 1965 and 1980 and the individuals born after 1980 are known as The Millennials or Generation Y (Lancaster & Stillman, 2002). Each generation has a set of characteristics by which they are defined. These characteristics include their approaches towards their work, technology and family.

Silent Generation (1925-1945)

The Silent Generation is also known as the Traditionalists. This generation was raised during World War II, and has undergone some of the hardest times when compared to all the other generations (Strauss & Howe, 1991). Their opinions towards family, religion, work and the government were deeply affected by the situations that had arisen during the Great Depression and the World War II. Influenced by the Great Depression and World War II this generation is known to be conservative, disciplined and have a sense of obligation towards the company for which they work. They like formality, a chain of command, need of respect and prefer to make decisions based on issues that have affected them previously (Zemke, Raines, & Filipczak, 1999). They also consider work to be their duty, and they always
have an obligation to the organization for which they work (Lancaster & Stillman, 2002; Kupperschnidt, 2000).

**Baby Boomers (1946-1964)**

The Baby Boomers got their name because there was an increase in the birthrate when many troops came home from World War II. The Boomers grew up in times of economic and educational expansion, which lead them to embrace an attitude of entitlement—an entitlement to and an expectation to obtain the best from life (Smola & Sutton, 2002). This generation was brought up to respect people of authority, but as they witnessed their idiosyncrasies, they learned not to trust anyone over 30 (Karp, Fuller, & Sirias, 2002). Their period of growth was prosperous; and hence, they are known to be idealistic, optimistic and responsible for many social movements in American history like the Civil Rights movement and the Women’s movement (Lancaster & Stillman, 2002). The Baby-Boomer generation, approximately 85 million strong, are the largest cohort currently in the workplace and the one associated with a large number of leadership positions (Trunk, 2007). The large size of this generation has been a cause for an increase in competition for resources and opportunities. In 2008, the oldest Baby Boomers turned 62 and most of them are in the middle or late period of their careers. In the next 25 years, the entire generation is expected to reach their traditional retirement age (Callanan & Greenhaus, 2008). The individuals of this generation have been characterized to believe that success can be achieved only through hard work and sacrifice. They are considered to be workaholics who prioritize their careers, believe in paying dues, familiar with step-by-step promotion and seek meaning in their life from their work (Kupperschnidt, 2000; Raths, 1999; Strauss & Howe, 1991). The Boomers, being confident task completers, want their achievement to be recognized, but may be insulted by constant feedback (Glass, 2007). Although they have been characterized as being goal-oriented, they are known to be more process-oriented rather than results-oriented. They are also known for their optimism and intuition to avoid conflicts in the workplace (Zemke et al., 1999). The individuals of this generation value health, wellness, personal growth and gratification and also seek job security (Raths, 1999).

**Generation X (1965-1980)**

Around 33 percent of the U.S. population belongs to Generation X, which were born between the years 1965 and 1980 (Bureau of Labor Statistics in AARP, 2007). The ‘X’ in Xers refers to the namelessness of the group (Beutell & Wittig- Berman, 2008) because they are considered to be a group of individuals without a clear identity; having generally diminished expectations; and feelings of alienation, pragmatism, conservatism and detachment (Corbo, 1997). Generation X is described as cynical and skeptical (Lancaster & Stillman, 2002). This may have been the response to witnessing many negative events while growing up which included an increase in crime and divorce rate (Losyk, 1997). This generation had both parents working; and, hence, they are also known as latchkey kids because they were taking care of themselves everyday (Kupperschnitt, 2000; Strauss & Howe, 1991). This may have been the reason that individuals of this generation developed skills of independence, adaptability and resilience (Thiefoldt & Scheef, 2004). Their untrustworthiness of the corporate sector may have been the influence of seeing their parents getting laid off even though they spent all their time at work (Kupperschnitt, 2000). Work is a difficult challenge, and they believe in working smarter rather than harder (Lancaster & Stillman, 2002). Unlike the Boomers, they do not define themselves based on the career path they have or will achieve. When dissatisfied with things at work, they will leave and find another job. They have very little loyalty towards their company, but would place their loyalty with their peers and their immediate supervisor. They look towards improving their career security rather than concentrating on job security. They value continuous learning and skill development and
are ruled by a sense of accomplishment (Bova & Kroth, 2001). Their approach towards solving problems in the workplace is practical and even though there is a great amount of research that confirms the cynical nature of individuals of this generation, there is evidence that they are motivated to achieve, self-starting and resourceful (Strauss & Howe, 1991; Lancaster & Stillman, 2002).

**Generation Y or Millennials (1981-2000)**

This generation is also referred as the Millennial, Nexters and Echo Boomers. According to the Bureau of Labor Statistics in 2007, Generation Y comprises 25 percent of the U.S. workforce.

Millennials do not have a long-term attachment or commitment towards the organization and regard their job as a means for building their career resume (Howe & Strauss, 2000). The Millennials regard fun in the workplace, not as a benefit, but as a requirement, unlike the Boomers who oppose workplace fun and Xer’s who are mostly indifferent towards workplace fun. They are also known as the “Trophy Generation” or “Trophy Kids” because of the trend to reward everyone for participation rather than rewarding only the winners. Members of this generation are described as people with confidence, conventional, optimistic, and socially conscious and being civic-minded. They prefer collective action and team work and desire to have flexibility in their work schedules. They grew up with technologies in abundance and modern ones being developed regularly and are considered to be digital natives. They are generally unafraid of new technologies and are usually the first ones to try, buy and spread word about new gadgets and technologies (Glass, 2007). Having access to technology and the Internet has been a source for exploring the world and getting information instantaneously (Zemke et al., 1999). They have a preference towards working with clear expectations and a desire to maintain a well-defined career path (Westernam & Yamamura, 1996). Unlike the Boomers, this generation is unwilling to dedicate much of their daily life to work. They prefer having a balance between their work life and other interests (Smola & Sutton, 2002). Having been raised in an environment with constant feedback, individual attention and praise, they expect the same level of feedback from the workplace in terms of individual development in the workplace (Ng, Shweitzer, & Lyons, 2010).

**METHODOLOGY**

Based on the literature studied and the objectives that are to be achieved, a survey questionnaire to measure the perceptions of industry with respect to the current workplace attributes was developed for students in a mid-size public university located in the southeastern part of the United States and the employees associated with construction companies that are located in the same region. The questionnaire was structured to obtain responses from questions in the format of rank order scale, Likert-scale and multiple choice. The first section of the questionnaire requested data about the age of the respondent, their status in the construction industry and the level of experience the respondent has in the construction industry. The next section consisted of rank-order and multiple choice questions that would solicit input on the opinion of the students and employees about the requirements of a construction industry workplace. This includes the workplace attributes, benefits, opportunities of career improvement, rewards, training, ways to attain work-life balance, and opportunity of travelling. The next section consisted of a series of questions that evaluated their opinion on the work habits that are being practiced in the construction industry. These questions also included statements in the literature that older generations stated as the least favorable characteristics of the millennial generation.

The participants in the study were students of the Department of Construction Science and Management (CSM) at Clemson University and construction industry employees of the Industry
Advisory Board (IAB) and Corporate Partners. The Construction Science & Management Department offers a comprehensive educational program designed to produce motivated, well-educated, responsible citizens with the management and technical skills requisite for leadership positions in the construction industry. The university is located in the southeastern part of the United States. The department offers both undergraduate as well as graduate programs with an enrollment of around 180 undergraduates and 25 graduate students. The department not only provides classes on the campus, but also has a master’s program through distance learning and interacts with various firms in the construction industry through student chapters and guilds associated with the department. Apart from having these provisions, the department has an Industry Advisory Board and Corporate Partners that are comprised of members from the industry that help provide assistance and guidance to the CSM department. For the purpose of this research members of the Industry Advisory Board and the Corporate Partners will be referred to as Construction Industry Employees (CIE).

Convenience sampling was considered for the purpose of this study. One of the populations considered are the employees of the construction industry. Since the research was based on understanding the generational differences of the workplace in the construction industry, questions related to the level of experience and their job position in the construction company was not considered. The second group of respondents considered comprised of students. The millennial generation is not homogeneous. Each person’s values and attitudes may differ by race, gender and their social and economic background they have been associated with. They may not have realistic expectations of the environment, attributes and practices in a professional work environment. The findings or results merely represent the expectations and choices of a professional workplace in the construction industry. Furthermore, the students with previous work experience may have been dissatisfied with their experience in the industry and it is unknown whether this issue may have had an impact on the participants’ work values. Both the samples of the population considered were restricted to a single geographical area of the United States. The relatively small size and geographical restrictions may have biased the results of the survey.

The questionnaire was distributed via survey monkey to the Construction Industry Employees that are located predominantly in the southeastern states of the US. After the results were obtained, the raw data was formulated in an excel file for analysis. The analysis of data obtained was done using one-way analysis of variance, chi-square test for independence and t-test for means using a 95% confidence level to determine statistical significance.

FINDINGS

The survey was distributed to 103 students from sophomore, freshman, junior, senior and graduate level of classes. There were 42 survey links sent to construction industry employees. There was a 100% response rate from the students and a 62.5% (N=25) response rate from the construction industry employees. Of the total of 128 responses, 19.6% (N=25) of the respondents belonged to the Construction Industry Employees and 80.4% (N= 103) of the respondents were CSM students at Clemson University. Also, 113 (or 88.28%) of the respondents belonged to the millennial generation, 8 (or 6.25%) to Generation X and 7 (or 5.47%) to the Baby Boomer generation. Of the 113 respondents belonging to the millennial generation, 103 respondents were students and 10 belonged to the population of Construction Industry Employees (CIE). Only 20 (or 19.42%) of the respondents belonging to the population of students (N= 103) had no experience working in the construction industry. A summary of the respondents is shown in Table 1.
Table 1: Distribution of respondents in the survey

<table>
<thead>
<tr>
<th></th>
<th>STUDENT</th>
<th>EMPLOYEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millennial (&lt;33)</td>
<td>103</td>
<td>10</td>
</tr>
<tr>
<td>Generation X (34-49)</td>
<td>—</td>
<td>8</td>
</tr>
<tr>
<td>Baby Boomer (50-68)</td>
<td>—</td>
<td>7</td>
</tr>
<tr>
<td>Silent Generation (&gt;69)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total no. of respondents</td>
<td>128</td>
<td></td>
</tr>
</tbody>
</table>

To understand the expectations of the millennial generation about the attributes of the workplace in the construction industry, three aspects were considered for the purpose of the research: work, home, and community. To analyze the work preferences of the millennial generation, ranking-type questions regarding workplace attributes, benefit packages, rewards and training/development opportunities were considered. The first aspect measured to analyze the perspective of the millennials are the workplace attributes when he/she considers a job in the construction industry. Out of the 103 student responses, 54 (or 52.43%) of them ranked ‘job security and career advancement opportunities’ as their top priority. Similarly, 13 responses of the 25 responses (or 52%) from the construction industry employees ranked it as their top priority. ‘Competitive pay and benefits’ is another attribute considered to be top priority for 25.24% of the student respondents and 36% of the construction industry employee respondents. Around 40% of the student respondents considered ‘health and dental insurance’ as their top priority while 52% of the construction industry employees considered ‘incentives and rewards based on performance’ to be their top priority amongst the given benefit packages offered by the construction firm. In terms of the rewards to be offered by the company, 87% of the student responses and 64% of the construction industry employee responses ranked ‘bonus’ as their top priority. Extra time off was another priority considered by 28% of the construction industry employee respondents. When asked about training/development opportunities a majority of both populations ranked ‘Continuing education workshops and seminars’ as their top priority. Some of the respondents marked ‘location of job’ to be their top attribute when they considered a job in the construction industry.

The other aspect considered for the purpose of this research is how the millennial generation achieves a work-life balance and their perspective of community service while working in the construction industry. While a majority of the construction industry employees considered ‘flexible work hours’ as their top priority, the millennials divided their priority between ‘flexible work hours’ and ‘travel distance from work’. When ranking the community services that are of high priority, millennials considered ‘volunteer opportunities in the community’ while a majority of the construction industry employee’s ranked ‘membership in professional societies’ as their top priority. The null hypothesis for each of the aspects states that there is an unequal probability that the respondents pick the attributes. The one-way ANOVA analysis resulted in a significant F-value thus rejecting the null hypothesis. This analysis deducts that the respondents had an equal probability of selecting any of the attributes considered for both home and community. Based on the ranking priorities of each group of respondents and the significance of the results achieved, the attributes considered to be of top priority by a majority of the respondents are shown in Figure 1.

Another criterion considered to be important in the construction industry is the amount of travel required on a daily basis as well as considering travelling as a part of the job description offered. Of the...
entire sample, 60 respondents (53%) of the millennial generation consider travelling as an opportunity. Around 81 of the millennial respondents prefer to travel less than 50 miles on a daily basis. The other respondents considered travelling up to 100 miles but very few people considered travelling more than 100 miles on a daily basis. Chi-square test of independence was performed to examine the relation between different generations and their preference to travel. The relations between the variables was significant, $\chi^2 (2, 128) = 26.85, p = 0.05$. This shows that millennials consider travelling as an opportunity.

Figure 1: Work place attributes perceptions: Students vs. CIE

In order to understand other parameters the millennial generation and employees considers for the ideal workplace, questions related to job performance, social activities in the work place, communication methods, the environment of the workplace and technology were asked. Respondents were asked to rate each statement based on a Likert-type scale of: 1= strongly disagree, 2= Disagree, 3= neither agree nor Disagree, 4= Agree, 5= strongly agree.

To get an insight on the different factors that improve ‘job performance’, statements that included close supervision and job performance reviews were considered. Millennials are split on the neither agree nor disagree (33.01%, N= 103) vs. agree (33.98%, N=103) that ‘close supervision improves their job performance’ while the construction industry employees agree (54.17%, N= 25) with the statement. When asked their opinion about ‘job performance reviews’ both the construction industry employees and the millennials strongly agree that the performance reviews are to be taken seriously (58.33%, N= 25; 49.02%, N= 103). To consider their attitude towards ‘formality in workplace’ both millennials and the construction industry employees appreciated formality in speech and dress in the workplace. The construction industry employees (54.17%, N= 25) agree with the statement ‘enjoy attending company sponsored events’, while the millennial generation disagree with that statement (38.24%, N= 103). To understand their perceptions about ‘methods of communication’, both the millennial generation and the construction industry employees are inclined towards the preference of communicating in person rather than using electronic methods. In terms of ‘receiving important information and updates by impromptu meetings’, the majority
of the employees agree (75%, N= 25) with the statement and 51.46% of the millennial generation (N= 103) agree with that statement. When asked if they would look at other ‘job opportunities’ and remain loyal to their existing employers, a majority of both the millennial generation and the construction industry employees agreed with the statement. Figure 2 and Figure 3 denote the frequency of responses on the Likert scale of the students and construction industry employees with the statements related to the environment of the workplace in the construction industry.

**Figure 2: Work place environment in construction industry- Student Perceptions**

**Work place environment-Student Perceptions**

- Impromptu meetings to receive information
- Employee should be involved in decision making on the project involved
- Effectiveness of an employee solely based on results they achieve
- Considering jobs opportunities at other organizations
- Job performance reviews considered seriously
- Close supervision improves performance

**Figure 3: Workplace environment in construction industry - Employees Perceptions**

**Work place environment-Employees Perceptions**

- Impromptu meetings to receive information
- Employee should be involved in decision making on the project involved
- Effectiveness of an employee solely based on results they achieve
- Considering jobs opportunities at other organizations
- Job performance reviews considered seriously
- Close supervision improves performance
To understand the view of the samples of the population on working individually or as a team the aspects of their working preference and the effectiveness were considered. While millennials were split on the neither agree nor disagree (34.95%, N= 103) vs. agree (38.83%, N= 103) on their preference of working on group projects than individual projects, a majority of the construction industry employees neither agreed nor disagreed (45.83%, N= 25) with the statement. When asked their opinion on team work being more effective in accomplishing projects, the construction industry employees stood by the neither agree nor disagree (45.83%, N= 25) while students strongly agreed (33.01%, N= 103) with that statement. However, both construction industry employees and millennials agreed (45.83%, N= 25; 49.51%, N= 103) with the statement of increasing productivity in a workplace by having competition amongst coworkers. ‘Flexible work hours’ are considered to be a priority by the millennials (41.75%, N= 103) associated with the construction industry but the employees were split between neither agree nor disagree (37.50%, N= 25) vs. agreeing (37.50%, N= 25) with the statement.

To understand the perception of technological advancement in the company the aspects of incorporating technology and keeping up with latest technology were asked. Employees strongly agreed (50%, N= 25) that the company should be associated with the latest technology to create a competitive opportunity while a majority of the students agreed (53.92%, N= 103) with the same and both samples of the population were in agreement (46.53%, N= 103; 62.50%, N= 25) with their comfort level of learning and keeping up with changes in the technology.

The research is based on a data obtained from a mix of generations in the construction industry as students and employees. However, the sample considered was for convenience of the research and the sample size being small may cause a possibility of biased results. While literature states that the millennial generation is associated with stereotypes, this study shows that the millennials think much similarly to the other Baby Boomers and Generation X respondents belonging to the construction industry. This can be seen in their preferences of work place attributes. Table 2 shows the preferences of the majority of responses ranked in the top two positions. One of the attributes considered to affect the preference of the workplace by both the millennial generation and the construction industry employees is the geographical location of the workplace or the jobsite. This shows that the perception of the millennials is not very different from the other generations working in the workplace. This may contradict the research done by Ng et al., 2010 that the perceptions of the younger generation and the Baby Boomers differ in terms of workplace attributes and expectations.

The research data also show that the millennials consider close supervision and job performance reviews to improve their performance on the jobs. This enhances the statement that the millennial generation expect the same level of feedback that they have received throughout their upbringing in terms of development in the workplace from their supervisors/mentors/employers according to Ng et al., 2010. They also appreciate formality in the workplace which contradicts the SHRM study (Burke, 2004) that the millennials prefer an informal workplace. The millennials also have a strong preference to work in teams and group projects and consider that as a factor to be more effective in accomplishing the project when compared to work individually on the project. They consider technology to be a factor to create a competitive environment and also agree that they are comfortable with keeping up to date with the latest technologies. Apart from that they believe in competition amongst co-workers to increase productivity in the workplace. The millennials, according to this research study, consider
flexible work-hours to be a priority to meet personal or family commitments and give less consideration to working more than 60 hours a week on a regular basis. This enhances research studies (Dries et al., 2008; Hewlett et al., 2009; Kowske et al., 2010; Smola & Sutton, 2002) that state that millennials prefer a work-life balance when compared to the earlier generation. The results of the research study show that a majority of the millennial generation prefers working in a company with a formal organizational structure and following an established chain of command, but does not prefer attending company sponsored social events for employees and their families. This shows that the population of this study has a preference of keeping their personal life and work life separate from each other.

Table 2: Perceptions of the workplace attributes by the majority of respondents

<table>
<thead>
<tr>
<th>Workplace Attributes</th>
<th>STUDENTS PERCEPTION</th>
<th>EMPLOYEE PERCEPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank 1</td>
<td>Job security and career</td>
<td>Job security and career</td>
</tr>
<tr>
<td>Rank 2</td>
<td>Competitive pay and benefits</td>
<td>Competitive pay and benefits</td>
</tr>
<tr>
<td>Benefit Packages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank 1</td>
<td>Health and Dental Insurance</td>
<td>Incentives and rewards based</td>
</tr>
<tr>
<td>Rank 2</td>
<td>Incentives and rewards</td>
<td>Health and Dental Insurance</td>
</tr>
<tr>
<td>Rewards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank 1</td>
<td>Bonus</td>
<td>Bonus</td>
</tr>
<tr>
<td>Rank 2</td>
<td>Extra time off</td>
<td>Extra time off</td>
</tr>
<tr>
<td>Training/Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank 1</td>
<td>Continuing education</td>
<td>Continuing education</td>
</tr>
<tr>
<td>Rank 2</td>
<td>Additional university degree</td>
<td>Additional university degree</td>
</tr>
<tr>
<td>Achieve Work-Life Balance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank 1</td>
<td>Flexible work hours</td>
<td>Flexible work hours</td>
</tr>
<tr>
<td>Rank 2</td>
<td>Travel distance from work</td>
<td>Travel distance from work</td>
</tr>
</tbody>
</table>

The research data also show that the millennials consider close supervision and job performance reviews to improve their performance on the jobs. This enhances the statement that the millennial generation expect the same level of feedback that they have received throughout their upbringing in terms of development in the workplace from their supervisors/mentors/employers according to Ng et al., 2010. They also appreciate formality in the workplace which contradicts the SHRM study (Burke, 2004) that the millennials prefer an informal workplace. The millennials also have a strong preference.
to work in teams and group projects and consider that as a factor to be more effective in accomplishing the project when compared to work individually on the project. They consider technology to be a factor to create a competitive environment and also agree that they are comfortable with keeping up to date with the latest technologies. Apart from that they believe in competition amongst co-workers to increase productivity in the workplace. The millennials, according to this research study, consider flexible work-hours to be a priority to meet personal or family commitments and give less consideration to working more than 60 hours a week on a regular basis. This enhances research studies (Dries et al., 2008; Hewlett et al., 2009; Kowske et al., 2010; Smola & Sutton, 2002) that state that millennials prefer a work-life balance when compared to the earlier generation. The results of the research study show that a majority of the millennial generation prefers working in a company with a formal organizational structure and following an established chain of command, but does not prefer attending company sponsored social events for employees and their families. This shows that the population of this study has a preference of keeping their personal life and work life separate from each other.

However, there was no significance for the data obtained from the statement that millennials do not mind working more than 60 hours a week and their preference of working in a company with an organized structure vs. an unorganized structure. Another common stereotype attached with the millennials is their method of communication. Based on literature by Zemke et al., 2000; Solna & Hood, 2008, the results state that the younger generation consider communicating by electronic methods rather than communicating in person. The research conducted for the considered sample of the millennial generation students in the construction industry proved otherwise; they prefer communicating in person rather than by electronic methods and welcome impromptu meetings to receive important information and updates. Though the millennials considered for the purpose of this research do not consider working more than 60 hours a week being a salaried employee, they do not mind working overtime if a project is behind schedule until the project is back on schedule. They consider travelling as an opportunity if it is a part of the job description, but also consider travel less than 50 miles on a daily basis to a job site.

This research study indicates that the millennial generation may have differences in the preference of the workplace in the construction industry when compared to other generations, but their priorities are however similar to the other generation construction industry employees. While most of the stereotypes attached to the millennial generation are considered to be applicable for millennials in the construction industry, there are a few stereotypes that are not applicable to this research study for the considered sample. However, the results obtained from the respondents may be biased because of the small sample size of the population and its restriction to only one geographical area of the United States.

CONCLUSIONS AND RECOMMENDATIONS

This research study used the framework of work, family and community to examine the ideal workplace attributes that the millennial generation considered in the construction industry. Unlike many research studies that state that the perspective of the millennial generation is completely different from the perceptions of the previous generation, the millennials of the construction industry prove to disagree. While the employers of the construction industry
concentrate on finding how different the millennials view the workplace, responses show that the millennials may not have a completely altering view of the workplace in the construction industry when compared to the other generations. This research study shows that although the millennials have different expectations of the workplace, they are very much similar to the attributes that current employees of the construction industry who belong to different generations. Based on the results obtained from respondents considered in this research study, the preferences of the millennial generation in the workplace of the construction industry are:

- Flexible work hours to meet family/personal commitments.
- Believe in team work and job performance reviews.
- Do not mix personal and work life.
- Prefer to communicate in person rather than using electronic methods and do not mind impromptu meetings to receive important information.
- They prefer using the latest technologies and do not mind learning and keeping up with the changes.

Some of the other common cited considerations by the respondents having the dream job with a perfect work environment are:

- Competitive work environment with challenging projects.
- A structured environment that allows free means of communication amongst the employees and employers.
- Balance of work and family life.
- Benefits in terms of paid vacations or extra days off.
- Work should not be restricted to the home office but should involve active participation at the project site.

It is recommended that with a larger sample of the population, other aspects such as the number of years of experience in the construction industry and the job position of the respondents should be considered to analyze if there are differences with respect to the level of experience and the position they are associated with in the company. Due to the lower number of responses obtained from employers in the construction industry, they were considered as construction industry employees for the purpose of this research. However, obtaining a higher response rate from the employers would give their preferences of the workplace. This will help in a comparative analysis of the expectations of the construction industry workplace from two aspects such as generational differences and student-employee-employer expectations.

The millennial generation comprises of the individuals that represent the workforce of the future. Hence, the findings reported in this research can inform employers on how to best attract and engage the next generation of skilled workers. The millennial generation has a capability to encompass their knowledge and skills to fulfill both personal and societal goals. This proves to be an opportunity that employers of the construction industry to fulfill the missions of their organization in serving the community. While the millennial generation have their own drawbacks, if effectively managed and retained they have the potential to become one of the great generations to serve in the construction industry.
REFERENCES


ABSTRACT

The objective of this study was to determine if warm mix additives currently used in Arizona can be added for the production of an Asphalt Rubber - Asphaltic Concrete Friction Course (AR-ACFC) without detrimental effects on performance of the pavement. Three warm mix additives (Evotherm®, Sasobit®, and Advera®) approved by Arizona Department of Transportation were investigated through a laboratory study along with statistical analysis. Three major concerns on performance of an AR-ACFC considered in this study are asphalt draindown, durability, and moisture susceptibility. The laboratory binder test results show there is no clear evidence that the use of Sasobit may need to be evaluated carefully because it tends to increase the binder stiffness at elevated temperatures. The mix performance test results show all additives do not have any detrimental effects on AR-ACFC mixes when draindown and moisture damage are concerned. For durability, the Evotherm and Sasobit mixes may cause more abrasion than regular AR-ACFC mixes, when the dosage level is deviated from the target level. With a target dosage, no negative impact is observed for all additives.

Keywords: Asphalt Pavement, Warm Mix Asphalt, Open Graded Friction Course, Asphalt Rubber, Statistical Analysis

Authors

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INTRODUCTION

Warm mix asphalt (WMA) is a general term for technologies that reduce temperatures needed to produce and compact asphaltic concrete mixtures for pavement construction by decreasing the viscosity of asphalt cement. Conventional hot mix asphalt (HMA) is produced at an approximate range of 140 to 160 °C, while WMA is produced at an approximate range of 100 to 140 °C. Over the last several decades, significant research effort exerted by both academia and industry developed viable warm mix technologies. A recent survey by the National Asphalt Pavement Association (NAPA) states there are about 30 WMA technologies available in the United States, although not all of these are widely used (Hansen et al. 2014). These technologies normally fall into four groups: chemical additives, organic additives, chemical foaming additives, and hot-mix plant water-injection foaming systems. NAPA found that hot-mix plant water-injection foaming systems are the most popular WMA technology, consisting of 87% of the market of the United States (Hansen et al. 2014). In general, the potential benefits of using WMA technology to produce asphaltic concrete have been identified as follows: reduced fuel usage, extended paving season, increased workability and compaction, reduced plant emissions, increased use of recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS), and improved working conditions for paving crews.

Along with the WMA technology, the use of asphalt rubber in either dense-graded or open-graded friction course (OGFC) mixes also provides significant benefits to the asphalt pavement through reduced reflection cracking, reduced pavement noise, and increased durability (Huang et al. 2012). The increased durability is of particular value because it results in reduced raveling of the rubberized OGFC mixture. However, it has been widely known that the introduction of asphalt rubber into an asphalt concrete mixture tends to increase the stiffness of the mixture thereby reducing its workability. To counter this reduction in workability, the mixtures are placed at higher mixing and compaction temperatures, which may cause more energy consumption and produce more emissions during the construction process. As a result, asphalt rubber production is limited in some areas due to restrictions on allowable emissions. To overcome this drawback, the use of WMA technologies for asphalt rubber pavement construction could be a viable option because benefits from both the asphalt rubber and WMA technologies become maximized (Xiao et al. 2009; Akisetty et al. 2009; Akisetty et al. 2010a and 2010b; Hicks et al. 2010; Cao and Liu 2013).

The objective of this case study was to determine if the ADOT approved WMA technologies can be used for asphalt pavements constructed in Arizona without detrimental effects on performance, specifically focusing on the performance of AR-ACFC mixes. Three major concerns with performance of an AR-ACFC containing WMA are 1) draindown of the warm asphalt rubber binder during construction, 2) the resistance of the mixture to raveling (i.e., mix durability), and 3) moisture damage over the life of the pavement surface. Alongside the mixture evaluations, the rubber binder behavior was investigated when the WMA additives are added into the rubber binder. Three ADOT-approved warm mix additives (Evotherm®, Sasobit®, and Advera®) were evaluated through a series of laboratory tests. This paper presents the research findings from the laboratory evaluation of the three WMA additive technologies on AR-ACFC.

LITERATURE REVIEW

There are several previous studies conducted to observe the behavior of asphalt pavements that combine WMA with asphalt rubber. Recently in California, studies on using WMA
technologies for mixes containing asphalt rubber were completed by the California Pavement Preservation Center (Hicks et al. 2010), the Pavement Research Center (Santucci 2010), and University of California Berkley (Jones et al. 2008). These studies looked at the use of the additives for WMA production and concluded that the warm mix technologies with asphalt rubber would provide the combined benefits of WMA and asphalt rubber. More recently, the California Department of Transportation (CALTRANS) had eight WMA technologies on their approved list including five additive technologies and three water-injection technologies (CALTRAN webpage); among them, the most commonly used products in California have been identified as Sasobit®, Advera®, and Evotherm® (Hicks et al. 2010).

Akisetty et al. (2009 and 2010a) conducted an extensive experimental study on warm rubberized asphalt using two warm mix additives: Asphamin® and Sasobit®. The study investigated the mix volumetric properties and binder rheological properties of rubberized asphalt containing the two additives. The conclusion of the study at large was the additives did not negatively impact mix and binder properties as compared with rubberized asphalt containing no WMA additives. In the same research, Akisetty et al. (2010b) also evaluated the engineering properties of the warm rubberized mixtures. The properties included indirect tensile strength (ITS), asphalt pavement analyzer, and resilient modulus. For all these engineering properties, the study found that there was statistically no significant difference between controlled group with no WMA additives and warm rubberized mix group.

Cao et al., (2012) also conducted a similar laboratory study to evaluate several engineering properties on stone matrix asphalt (SMA) containing three warm mix additives: Sasobit®, Evotherm®, and one unknown warm mix product. This study supported the Akisetty's results furthering the additives were overall not detrimental to the performance of rubberized asphalt pavement. Farshidi et al. (2013) evaluated asphalt rubber in both HMA and WMA with respect to emissions. It was found that the WMA technology type, the plant mixing temperature, and the level of compaction had a significant effect on the nature of emissions from the paving operations, indicating that WMA technologies have the potential for reducing emissions during construction of asphaltic concrete pavement.

Based on the author’s conversations (during February to March 2015) with contractors, industry representatives, and CALTRANS employees; the use of water-injection WMA technology for Asphalt Rubber - Asphaltic Concrete Friction Course (AR-ACFC) mixtures has had mixed success in California. There are reports of clumping the AR-ACFC with only a small reduction in temperature. But, according to the CALTRANS Flexible Pavement Materials Engineer (Dr. Kee Foo, telephone interview, March 24, 2015), the official position of CALTRANS is that all the WMA technologies on the CALTRANS list of approved additives are acceptable including water-injection systems.

Although the Florida Department of Transportation (FDOT) has not published research reports on their use of WMA technologies in asphaltic concrete mixtures, they do use WMA technologies. They allow the use of ten different technologies. Approximately 3 % of their total asphaltic concrete production uses a WMA technology: 67% water-injection foaming systems and 33 % chemical additives (Nash 2014). According to the FDOT bituminous engineer (Jim Musselman, telephone interview, March 13, 2015), Florida contractors had good success with all WMA technologies on the approved list when used in asphalt rubber mixes. In Arizona, the asphalt rubber practiced by Arizona Department of Transportation (ADOT) is very similar to that of CALTRANS; however, no research effort is found in evaluating the ADOT
approved WMA technologies on rubberized asphalt pavement.

**MATERIALS**

**Aggregates**

Aggregates used to produce the laboratory AR-ACFC mixtures were sampled from the ADOT approved individual aggregate stockpiles for an actual ADOT AR-ACFC project on State Route Loop 101 from 27th to 7th Avenue in Phoenix, Arizona. The contractor utilized three stockpiles to have the design aggregate structure of the AR-ACFC met the ADOT specifications. Portland cement Type II was added at a rate of 1% of the combined dry aggregates by weight, as an admixture. The gradation of the final aggregate blend passed the ADOT mix design requirements and the physical properties met the ADOT specifications as well. Table 1 presents the test values of the properties along with the specifications from the final aggregate blend.

**Table 1 Aggregate Properties and ADOT Specification**

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Result</th>
<th>ADOT Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasion at 100 revolutions (%)</td>
<td>4</td>
<td>max 9</td>
</tr>
<tr>
<td>Abrasion at 500 revolutions (%)</td>
<td>18</td>
<td>max 40</td>
</tr>
<tr>
<td>Sand equivalent</td>
<td>70</td>
<td>min 55</td>
</tr>
<tr>
<td>Two fractured faces (%)</td>
<td>96</td>
<td>min 85</td>
</tr>
<tr>
<td>Flakiness index (%)</td>
<td>20</td>
<td>max 25</td>
</tr>
<tr>
<td>Carbonates (%)</td>
<td>0.6</td>
<td>max 20</td>
</tr>
<tr>
<td>Combined Specific gravity</td>
<td>2.62</td>
<td>min 2.35, max 2.85</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>1.37</td>
<td>max 2.50</td>
</tr>
</tbody>
</table>

**Asphalt Binder and Ground Tire Rubber**

PG 64-16 was selected as a base asphalt binder type. The ADOT Superpave mix design for the AR-ACFC determined the optimum design binder content of 9.7%. The rubber tire scraps were mechanically produced by cutting and grinding at ambient temperatures. The crumb rubber gradation designed and used in this study, along with the ADOT specification, is presented in Table 2. To make a rubberized asphalt blend, the shredded tire scraps were introduced into the base binder at high viscosities, as the temperature of the binder was heated to 204 °C. This type of asphalt rubber blend is commonly referred to field blend as opposed to terminal blend. The asphalt rubber binder contained 19.0% crumb rubber by the weight of the total binder blend (classified as Type B according to ADOT Specification Section 1009). A specific gravity of the crumb rubber modifier was 1.15 which met the ADOT requirement of 1.15 ± 0.5.

**Table 2 Crumb Rubber Modifier Gradation**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Result (% Passing)</th>
<th>ADOT Specification for Type B Rubber Binder (% Passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#10, 2000 μm</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>#16, 1180 μm</td>
<td>83.9</td>
<td>65-100</td>
</tr>
<tr>
<td>#30, 600 μm</td>
<td>30.0</td>
<td>20-100</td>
</tr>
<tr>
<td>#50, 300 μm</td>
<td>10.6</td>
<td>0-45</td>
</tr>
<tr>
<td>#20, 75 μm</td>
<td>0.0</td>
<td>0-5</td>
</tr>
</tbody>
</table>
WMA Additives
Three ADOT-approved WMA additives were used in this study: Evotherm, Sasobit, and Advera. Evotherm is a special chemical acting as an emulsifying agent. It liquefies the traditional asphalt binder and thus significantly decreasing its viscosity. Sasobit is produced from coal gasification using a Fischer-Tropsch process forming a fine crystalline in flakes or power. It is a common practice that Evotherm and Sasobit are introduced into the asphalt rubber binder prior to mixing with aggregates. On the other hand, Advera is a granular material and it does not dissolve in the asphalt binder; therefore, it is directly blended when aggregates and rubber binder are mixed. Each of the three additives was added at three different concentration rates to simulate a typical range that might occur during field production of a WMA mixture. The target rate for each of the additives was recommended by the additive manufacturers. The additive rates used to conduct the laboratory analysis were as follows. Note that an abbreviated code to represent each group is presented in parentheses. The code for the control group is set as “No Add”.

Evotherm
• Below target – 0.25% by weight of asphalt binder (Evo-T1)
• At target – 0.40% by weight of asphalt binder (Evo-T2)
• Above target – 0.70% by weight of asphalt binder (Evo-T3)

Sasobit
• Below target – 0.50% by weight of asphalt binder (Sas-T1)
• At target – 1.5% by weight of asphalt binder (Sas-T2)
• Above target – 3.0% by weight of asphalt binder (Sas-T3)

Advera
• Below target – 0.15% by weight of asphalt concrete mixture (Adv-T1)
• At target – 0.25% by weight of asphalt concrete mixture (Adv-T2)
• Above target – 0.35% by weight of asphalt concrete mixture (Adv-T3)

EXPERIMENTAL PROGRAM
Asphalt Rubber Binder Testing
In accordance with ADOT Specification (Section 1009-2), ADOT requires asphalt rubber binder used on ADOT projects to meet the requirements with the following tests: Rotational Viscosity (AASHTO T316), Penetration (ASTM D5), Softening Point (ASTM D36), and Resilience (ASTM D5329). These tests were performed on asphalt rubber binders that were modified with Evotherm and Sasobit in order to evaluate the additives’ effects on the conformance of the asphalt rubber to the ADOT specifications. An unmodified asphalt rubber binder was also tested as a control sample for comparison purposes.

In addition to those four ADOT required binder tests, dynamic complex shear modulus testing (ASTM D7175) was performed on the asphalt rubber to determine its rutting parameter \((G^*\sin \delta)\) at different temperatures. This test was conducted to determine the pass/fail temperature for each of the original unmodified and WMA modified binders. The pass/fail temperature is defined as the temperature at which the asphalt binder being tested will have a test value \((G^*/\sin \delta)\) of 1 kilopascal (kPa). The pass/fail temperature is an indicator of the stiffness of the asphalt binder. The higher the pass/fail temperature is, the stiffer the asphalt binder is. In this study, this pass/fail temperature was used for a relative comparison in stiffness between original rubber binder and WMA modified rubber binders without specific criteria. As described, Advera was not used for this binder evaluation because Advera was not combined with binder prior to mixing with aggregates.

Table 3 summarizes the experimental conditions of each of the five binder tests used in this study along with the ADOT specifications. For each test, five measurements were made at different timings after adding each WMA additive: 60,
90, 240, 360, and 1440 minutes. For the last measurement at 1440 minutes, the rubber binder was maintained at 135 °C overnight and reheated to 177 °C in order to regain the consistency before the sample preparation.

Table 3 Asphalt Binder Test

<table>
<thead>
<tr>
<th>Test</th>
<th>Unit</th>
<th>Test Temperature</th>
<th>ADOT Spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational Viscosity</td>
<td>Pascal-seconds</td>
<td>177 °C</td>
<td>1.5 - 4.0</td>
</tr>
<tr>
<td>Penetration</td>
<td>0.1 mm</td>
<td>4 °C</td>
<td>10 min.</td>
</tr>
<tr>
<td>Softening Point</td>
<td>oC</td>
<td>N/A</td>
<td>57 min.</td>
</tr>
<tr>
<td>Resilience</td>
<td>%</td>
<td>25 °C</td>
<td>25 min.</td>
</tr>
<tr>
<td>Dynamic Shear (G*/kPa)</td>
<td>76, 82, and 88 °C</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Pass/Fail Temp.</td>
<td>oC</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Mix Testing
The effects of WMA technology on AR-ACFC mixes was evaluated with three mix performance tests: draindown, durability (abrasion resistance) and moisture susceptibility. The purpose of these tests was to evaluate the potential performance of a group of AR-ACFC mixes containing a WMA additive as compared to that of a control (no additive) regular asphalt rubber mix group.

Draindown testing is a common mix test that is widely used in the asphalt pavement community to determine the amount of asphalt binder loss of friction courses when a sample is placed at an elevated temperature from an ambient temperature (Cooley et al. 2009). Test specimens were mixed at 163 °C with two-hour oven curing and left at a room temperature for 24 hours prior to compaction and testing. The test was conducted at 135 and 163 °C following ASTM D6390.

Durability of the asphalt mixtures was determined by conducting the Cantabro test. In contrast to the draindown test, the Cantabro test identifies a minimum asphalt binder content since durability is improved as the asphalt binder increases (Cooley et al. 2009). For this study, the test was conducted on unaged and aged AR-ACFC mixtures. For the aged AR-ACFC mixtures, the mixture was placed in a two inch deep pan and placed into a forced draft oven at the compaction temperature of 163 °C. The loose mixture was aged for 48 ± 1 hour to simulate the pavement surface after several years of service.

Moisture susceptibility of the mixtures was determined by following AASHTO T283 with a minor modification. Three unconditioned (i.e., without soaking) specimens are prepared and an average of their indirect tensile strengths is calculated. Another three conditioned (with soaking cycles) specimen set is prepared and an average of their indirect tensile strengths is also calculated. The ratio of the average indirect tensile strength from the conditioned samples to that of the unconditioned samples is then calculated. This ratio is defined as the tensile strength ratio (TSR). The standard test procedure requires the conditioned specimens be vacuum saturated at 7% air voids. However, due to the open characteristics of the AR-ACFC (air voids of approximately 19%), this was not feasible for this study. To ensure that the AR-ACFC mixture did not disintegrate in the 60 °C water bath during the 24 hours of soaking, they were placed in a rubber sleeve for protection. Test specimens were mixed at 163 °C with two-hour oven curing prior to compaction. Due to the nature of the mix used, all mixing was performed by hand mixing and continued until full coating was obtained. No specific time frame was observed for mixing.
Data Analysis Method
A series of one-way analysis of variance (ANOVA) was performed to observe the mean difference among groups. When an initial ANOVA test failed to reject H0 (i.e., there is at least one group which mean value is significantly different from other group means), the Dunnett’s test was further used for a “comparison with a control” analysis. The Dunnett’s test compares mean values between control group and other individual group, one by one. For example, a control group is individually compared with an Evo-T1 group, an Evo-T2 group, etc. For ANOVA used in this study, a level of 95% significance (α=0.05) was used. The results of each binder and mix test are presented in a bar chart format. The bar chart is depicted with the averages and their error bars with respect to standard error.

The number of test samples varies with the type of testing. As mentioned in the previous section, five measurements were made at different timings for each group for all binder testing. Note that this binder property measurement scheme is in compliance with the ADOT specifications. For the draindown mixture test, triplicates were used per one set of testing. Since there were three sets of draindown testing, a total of nine replicates were used at each test temperature. In a similar manner, the durability (Cantabro) test used triplicates for one set of testing and the test was repeated three times (i.e., triplicates x three sets = total nine replicates) for each of unaged and aged condition. For the moisture susceptibility test, triplicate measurements were made for each of unconditioned and conditioned specimens; and out of the average of triplicates, one TSR value was calculated. The test was repeated three times and as a result three TSR values were used to obtain the statistics for each additive group. Table 4 summaries the number of measurements/replicates for laboratory tests conducted in this study.

<table>
<thead>
<tr>
<th>Binder or Mixture</th>
<th>Test</th>
<th>No. of Groups</th>
<th>Measurements or Replicates</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Rubber Binder</td>
<td>Viscosity</td>
<td>7</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Penetration</td>
<td>7</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Softening Point</td>
<td>7</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Resilience</td>
<td>7</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Complex Shear</td>
<td>7</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>AR-ACFC Mixture</td>
<td>Draindown at 135 °C</td>
<td>10</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Draindown at 163 °C</td>
<td>10</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Cantabro (Unaged)</td>
<td>10</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Cantabro (Aged)</td>
<td>10</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Moisture Susceptibility</td>
<td>10</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>(Unconditioned)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moisture Susceptibility</td>
<td>10</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>(Conditioned)*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TEST RESULTS, ANALYSIS, AND DISCUSSION

Asphalt Rubber Binder Test Results
The binder tests described in the previous section were conducted and the test results are presented in Figures 1 and 2. ADOT requires the viscosity of rubber binder be placed between 1.5 and 4.0 Pa-s at 177 °C. These limits have the asphalt rubber binders insured from making the mix extremely stiff or soft. The rotational viscosity results shown in Figure 1 (a) indicate all binders meet the requirement, meaning all the binders have a proper level of viscosity where the asphalt mix is properly produced. The error bar in the chart represents a standard error of each group. A one-way ANOVA test was conducted to see the statistical difference between the control group (No Add) and other treated groups. The results indicate there is statistically significant difference in viscosity with the Evo-T1 and Evo-T2 groups where these two groups have higher viscosities. However, the viscosity values are still within the ADOT requirements and for all practical purposes, the Evotherm treated binders are considered viable.

The penetration and softening point test results are included in Figure 1 (b) and (c), respectively. These two tests dictate the stiffness of asphalt rubber binder in a more intuitive way with a minimum requirement. The more the penetration depth is and the lower softening temperature is, the softer the binder is. Similar to the viscosity results, all groups meet the ADOT required minimum penetration depth of 1 mm at 4 °C, suggesting the treated rubber binders be workable, not too stiff, albeit the mean values of four groups (Evo-T1, Evo-T3, Sas-T2, and Sas-T3) have a statistical difference from the control group. The binders in these groups seem stiffer. In regard to the softening point results, two rubber binder groups (Sas-T2 and Sas-T3) show a noticeable difference from the control group. Especially, the Sasobit blend group at the above target dosage (Sas-T3) is peculiar. The softening temperature is 90 °C which is very higher than other groups although this blend still meets the minimum required softening point of 57 °C.

The resilience test is typically used as an indicator of elasticity of asphalt cement, particularly for sealant. ADOT adopts this testing to measure the ability of an asphalt rubber to reject incompressible objects from the surface layer. A minimum resilience of 25% is required to meet the ADOT specification. As presented in Figure 1 (d), the test results meet all the requirement. The ANOVA indicate the Sas-T1 and Sas-T3 are statistically different than the control group, but they all meet the ADOT requirements.

Figure 1: Rubber Asphalt Binder Physical Test Results (a) Rotational Viscosity at 177 °C

![Figure 1 (a)](image)
The dynamic shear test results are included in Figure 2. Figure 2 (a) depicts the complex shear modulus divided by its phase angle ($G^*/\sin \delta$) for each blend group at three different temperatures (76, 82, and 88 °C). This elastic portion of the complex shear modulus should be large enough to resist rutting and hence a minimum $G^*/\sin \delta$ value is usually specified to dictate rutting potential. The Performance Graded (PG) Asphalt Specification in the Superpave mix design suggests that $G^*/\sin \delta$ be greater than 1 kPa at the high PG temperature for the original binder condition and 2.2 kPa for the short-term aged binder (Roberts et. al. 1996). Note that ADOT does not dictate $G^*/\sin \delta$ in their rubber binder requirement. This testing was performed to observe the binder characteristic for a relative comparison purpose. In the figure, the three Evotherm groups and the Sas-T1 group did not show any significant difference from the control group, whereas the Sas-T2 and T3 groups showed quite higher stiffness than the control group, in particular at 76 and 82 °C. The ANOVA results also indicate that there is a statistical difference in $G^*/\sin \delta$ in Sas-T2 at 76 °C and Sas-T3 at all three temperatures. The trend in stiffness in the Sasobit groups appears to increase. This result is in agreement with the penetration and softening point test results.

The pass/fail temperatures for all groups were similar as evident in Figure 2 (b). This result implies that, at a relatively lower temperature, the Sas-T2 and Sas-T3 groups would be stiffer, but at an elevated temperature, the groups would rapidly lose its stiffness.
In summary, the results of physical binder property tests indicate that overall the two WMA additives (Sasobit and Evotherm) could be used in the rubber binder in Arizona. No serious negative effect was observed for all blend groups. Although ANOVA reveals that some groups show a statistically significant difference from the control group, as shown in Table 5, the groups still meet the ADOT requirements with no undesirable test results. Two Sasobit treated binder groups with target and above-target levels (Sas-T2 and Sas-T3) show a peculiar behavior in an elevated temperature. They become significantly stiffer than the other groups. This is in fact no detrimental to the pavements in a hot region like Arizona, because a stiffer mix at a high temperature would rather be preventive and protecting from rutting distresses.

Table 5: Summary of ANOVA for Asphalt Rubber Binder Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Evotherm</th>
<th>Sasobit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evo-T1</td>
<td>Evo-T2</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Penetration</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Softening Point</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Resilience</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>G*/sin δ at 76 °C</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>G*/sin δ at 82 °C</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>G*/sin δ at 88 °C</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Pass/Fail Temperature</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>
MIX TEST RESULTS

Draindown
As described previously, the draindown test is performed to see the potential loss of asphalt binder at high temperatures during production, particularly applicable to open-graded friction courses. Although ADOT does not explicitly dictate the mix requirement for draindown in the specification, it is a major concern of ADOT in the mix design process. The draindown test results are summarized in Table 6. As evident, the results show that any of the additives had absolutely no discernible effect on the draindown characteristics of the AR-ACFC mixtures at both test temperatures: 135 and 163 oC. No statistical analysis was conducted for this test as it is obvious that there is no statistical difference among groups.

TABLE 6: Summary of Draindown Test Data Percent Binder Loss

<table>
<thead>
<tr>
<th>ADDITIVE</th>
<th>Evotherm 135 oC</th>
<th>Evotherm 163 oC</th>
<th>Sasobit 135 oC</th>
<th>Sasobit 163 oC</th>
<th>Advera 135 oC</th>
<th>Advera 163 oC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Additive</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Below Target (T1)</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>At Target (T2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Above Target (T3)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Durability
The Cantabro test result of lab-prepared AR-ACFC samples containing each of the three WMA additives was compared with that of the no-additive control AR-ACFC sample group. Two bar charts were created as shown in Figure 3. Figure 3 (a) presents the unaged sample Cantabro percent loss. The ANOVA test revealed that the Evotherm mixes with the below-target and at-target dosage levels (Evo-T1 and Evo-T2) and the Sasobit mix with the target dosage level (Sas-T2) showed a statistically significant difference from the no-additive control mix. The percent loss for the unaged samples of these three blend groups is a lot higher than that of the no-additive control group. All Advera mix groups look comparable to the control group.

A similar statistical analysis was conducted for the Cantabro results of the aged AR-ACFC mix sample groups (Figure 3 (b)). The ANOVA test indicates the Evotherm mix at a below-target dosage and the Sasobit mix at an above-target dosage (Evo-T1 and Sas-T3) have approximately 20% larger Cantabro abrasion. For the Advera mixes at all dosage levels, it should be recognized that, although the Dunnett’s test revealed there were differences in the means of all the mixes, the Cantabro results for the mixes are in fact less than that of the control mix. This proves the durability performance of the Advera mixes is even better. At a target dosage level for all WMA additives, it was found all three aged mix groups had no negative impact on the durability performance.
Moisture Susceptibility

A similar analysis was also conducted to evaluate the AR-ACFC mix performance with respect to moisture susceptibility. The TSR values used in the analysis were calculated based on three sets of unconditioned and conditioned samples. Therefore, one TSR value is calculated with three replicates. Figure 4 summarizes the TSR results for all 10 groups. The ANOVA test indicates the Sasobit mix at an above-target dosage level (Sas-T3) was found to be the only mix which shows a significant difference in TSR. However, since the Sasobit mix has a higher TSR value, its performance is superior to the control group. Thus, it can be concluded that all WMA groups have no adverse effect on the moisture susceptibility regardless of the dosage levels.

In summary, it was found all three WMA additives did not have any negative effect on draindown and moisture susceptibility. For the durability test with unaged samples, the two Evotherm groups (Evo-T1 and Evo-T2) and one Sasobit group (Sas-T2) showed a negative effect. With the aged samples, one Evotherm (Evo-T1) and one Sasobit group (Sas-T3) showed a negative effect. All Advera groups had a statistical difference from the control, but their performance was even superior to the control group.
**Table 6: Summary of ANOVA for Mix Testing**

<table>
<thead>
<tr>
<th></th>
<th>Evotherm</th>
<th>Sasobit</th>
<th>Advera</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>Draindown</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Cantabro (Unaged)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Cantabro (Aged)</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>TSR</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

**CONCLUSIONS AND RECOMMENDATIONS**

Based on the results of this study with limited samples, several conclusions can be drawn. First, the use of Sasobit has a tendency to increase the stiffness of the asphalt rubber binder at elevated temperatures. The binder stiffness will increase rapidly as the dosage increases. Although adding Sasobit to the rubber binder at a target and above target dosage may be helpful in hot regions where a stiff binder is required, it is recommended that further studies be conducted to see its cracking potential due to excessive binder stiffness. Second, the use of Evotherm has overall little effect on the properties of the asphalt rubber binder. There are some statistical difference in viscosity and penetration between Evotherm groups and control group. However, the difference does not have any negative impact on the rubber binder, meeting the existing ADOT rubber binder specifications. Third, all three WMA additives (Sasobit, Evotherm and Advera) will be usable for the AR-ACFC mixes when draindown and moisture susceptibility are concerned. No detrimental effect will be expected. Four, Evotherm and Sasobit may cause durability issues, depending on the dosage level. For both additives, the durability performance has no difference from the control group at a target dosage level, but when the dosage level is changed, approximately 20% more abrasion loss is observed.

The practical implication from these technical conclusive remarks is that the three warm mix additives can be used in asphalt pavement constructions in Arizona without any serious negative impact on the end-product quality, when the mix is designed to incorporate asphalt rubber. ADOT recently completed a pilot field study using the three additives on asphalt rubber mix. The performance test results on the field materials were found to be in general agreement with the research results presented in this paper.

It should be noted that the conclusions may only be applicable to the local materials (i.e., aggregates and asphalt binder typically used in AZ). To make conclusions universal and generally acceptable to other states, it is recommended that other agencies consider similar type of studies in both laboratory and field with their own regional materials. Additionally, monitoring the long-term performance of the pavement will be key to the successful implementation of the warm mix technology on pavement design and construction.
ACKNOWLEDGEMENTS

The authors acknowledge the Arizona Department of Transportation for providing financial support for this study.

REFERENCES


Math Skills that Don’t Add Up; A Comparison between Eighth Grade and College Students

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ABSTRACT

Among 34 participating countries within the Organization for Economic Cooperation and Development (OECD), the United States performed below average in mathematics earning a rank of 27. The World Economic Forum (2014) ranks the United States 51 out of 144 countries scoring a 4.4 out of 7 (7 = excellent) in the quality of mathematics and science education. Although the United States’ competitive advantage and economic growth is directly connected to science, technology, engineering, and math (STEM) careers, only 28 percent of those students choose to major with these fields in college. In addition, 48 percent of students that choose to major within STEM fields will switch to non-STEM majors or leave college without completing a degree (Chen, 2013). Since construction management is a STEM-related field, these statistics are concerning. While basic foundational math principles are methodically established and advanced in the public school system from kindergarten through middle school, students’ growth within math appears to stagnate in high school. This could stem from the fact that high school students can opt out of math or complete all math requirements during their first year of high school. When students opt out of math or complete it early, these students go multiple semesters without a math requirement. The intent of this research is to show that abstinence from mathematics in high school can result in a lack of growth in math skills, which then becomes an unnecessary hurdle for university freshman entering into STEM majors such as Construction Management. Using a standard math exam that tests students’ knowledge and ability in regards to unit conversions, measurement, and basic geometry, this pilot study compares middle school exam results with those of university freshmen enrolled in STEM-related fields.

Keywords: STEM, Education, Math Skills, Middle-School, Careers

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Introduction

Basic foundational math principles are methodically established and advanced in the public school system from kindergarten through middle school. Conversely, during their high school years, students have the option of taking advanced math courses, completing basic math requirements early, or in some cases, opting out. Students who complete requirements early or opt-out will have one or more semesters without a math requirement. Research shows that lack of growth within mathematics has college freshmen struggling with what should be considered elementary and middle school math skills (ACT, 2004; Brown & Niemi, 2007). As the conversation continues across the United States regarding the rising cost and decreasing value of an undergraduate degree, students who choose fields related to science, technology, engineering or math (STEM), like construction management, earn an average of 19 percent more upon graduation (Vigdor, 2013). As educators and professionals within STEM-related fields, there is a high interest in retaining college freshmen, which may translate to working with high schools in regards to the consistency of mathematic requirements.

The United States is not in the top ranking among countries in regards to math and science education. Among 34 participating countries within the Organization for Economic Cooperation and Development (OECD), the United States performed below average in mathematics earning a rank of 27. The World Economic Forum (2014) ranks the United States 51 out of 144 countries scoring a 4.4 out of 7 (7 = excellent) in the quality of mathematics and science education. Although the United States’ competitive advantage and economic growth is directly connected to STEM careers, only 28 percent of those students choose to major with these fields in college, even though the rewards in salary dollars are much higher for students than in other fields. In addition, 48 percent of students that choose to major within STEM fields will switch to non-STEM majors or leave college without completing a degree (Chen, 2013). These results are telling of a mathematic decline beginning in the late 1970’s (Drew, 2015; Schmidt, 2012). Methodologies such as differentiation, common-core, and double-dose algebra all can play a role in slowing the decline. However, these initiatives unfortunately do not address the consistent and repetitious requirements often associated with reaching mastery levels of a subject, in this case fundamentals of mathematics. Multiple studies have reported college bound high school students being guided towards advanced math courses, yet those students who choose not to pursue secondary education are provided only basic math instruction in order to receive a diploma (Hall & Ponton, 2005; Long, Iatarola, & Conger, 2009). This specific approach could be potentially limiting to students who ultimately may be able to enter STEM fields such as construction or other applied science disciplines.

In an effort to understand the influence of a complex and varied high school math curriculum, the researchers measured basic math skills of eighth grade students and compared their scores to freshmen level students. It is the researchers’ hypothesis that middle school students will test at an equal or higher level than the freshmen college students when given the same basic math assessment. While these basic math skills are often retaught to students through remedial college courses, this study attempted to identify the K-12 school’s lack of growth as a possible factor of why college students are ultimately avoiding STEM-related career fields. By identifying limited, zero, or negative growth during high school, results from this study are intended to become part of the conversation for developing high school math curriculum. Consistent and repetitive mastery of basic math skills can ultimately increase the number of people pursuing either STEM education or employment; potentially offering a
partial solution to the work force crisis currently being experienced by many in the construction industry (Chen, 2013; Hall & Ponton, 2005).

**Literature Review**

Identification of possible reasons for the three-decade long decline in math skills has become a major research focus (Drew, 2015; Schmidt, 2012). National policy makers have continually offered legislation regarding math education as a national imperative. Both Gardner (1983) and Tate (1997) identify this change in educational measuring and standards specifically regarding mathematics. Both studies look at the implementation of standardized testing and the evolution of curriculum. Unfortunately, the findings fail to identify working solutions to the reduction in world rankings. Kilpatrick’s (2012) research looks at this continued decline by pointing to the National Assessment of Educational Progress having a historical focus on pure mathematics rather than applied mathematics as one possible reason.

This increase in standardized testing has allowed the United States to more accurately compare the education level amongst its peers, and confirms a steady drop in mathematic competency. In 2004, ACT conducted an in-depth study of math readiness along with other STEM-related topics. The study compares demographic information and presents a breakdown of competency based findings, in which only 40% of students met the basic benchmark for college Algebra readiness. Brown and Niemi’s (2007) findings show students in need of extensive math remediation required to complete STEM degrees. This coincides with Long, et al.’s (2009) study that found one-third of the nation’s college freshman unprepared for college-level math. Furthermore, this math inadequacy not only warns incoming freshman away from STEM-degrees but also has a direct effect on completion of a university degree (Hall & Ponton, 2005).

Roschelle et al. (2008) summarized a national math advisory panel report calling for mathematics to be the center of debate regarding K-12 education. The panel identified the consistency of math competencies in grades K-8 where schools developed a succession of adaptive reasoning, and mastery of particular skills and concepts. They then identify and make a compelling argument to continue this trend through high school that allows future learning and for the actual mathematical demands of their adult lives. Four recommendations of the 2008 advisory panel highlight include:

- The importance of particular topics such as rational numbers
- The coherence and closure in mathematics curricula
- The integration of concepts and procedures
- The need to boost teachers’ math knowledge

Other studies have shown a similar push for applied, concrete activities that push students to master advanced math concepts while learning critical thinking skills through a mentorship—consisting of university and community college members (Conley, 2005; Stone, Alfeld & Pearson, 2008).

Research pertaining to middle school students and math skills is less prevalent, but available. In 2014, a study conducted by the National Math and Science Initiative found 35% of eighth grade students performed at or above the proficient level in mathematics. A comparison study conducted by Vigdor (2013) looked at data collected during the middle school years during both the 1970 and 1980. While the 1980 American born students performed better in mathematics than their 1970 cohorts at ages 9 and 13, they lost their advantage by the time they reached 17. This study will attempt to expand
upon this research by comparing eighth grade and freshman level math skills. In performing this research, we hope to understand the adequacy of math skills within this age group and steps that may be taken to begin to address the reluctance of the next generation to enter STEM-related career fields.

**Methodology**
Using a vetted math exam that tests students’ knowledge and ability in the areas of fraction conversion, scale measurement, basic area, volume, probability and averages, and complex area and volume calculations, this pilot study compared middle school exam results with those of university freshmen enrolled in STEM-related fields. These STEM-related fields extended across four different college majors, including construction management. A math assessment test, developed by Jon Elliott, PhD, from Colorado State University and Dale Porter (author), was originally created to test initial math skills in a beginning construction class. The test called, “Construction Math and Measurement”, was used to assess basic needed math skills in the categories of fraction conversion, ruler measurement, simple and complex area and volume as well as probability and averages. Basic descriptive statistics for this study are shown in Table 1.

**Table 1: Descriptive Statistics Total and by Category**

<table>
<thead>
<tr>
<th>Questions</th>
<th>Category</th>
<th>Max score</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>All Questions</td>
<td>36</td>
<td>21.66</td>
</tr>
<tr>
<td>1 – 4</td>
<td>Fraction Conversion</td>
<td>16</td>
<td>11.55</td>
</tr>
<tr>
<td>5</td>
<td>Ruler Measurement</td>
<td>5</td>
<td>3.83</td>
</tr>
<tr>
<td>6 – 12</td>
<td>Simple Area and Volume</td>
<td>8</td>
<td>2.95</td>
</tr>
<tr>
<td>13</td>
<td>Probability and Averages</td>
<td>3</td>
<td>2.07</td>
</tr>
<tr>
<td>14 – 17</td>
<td>Complex Area and Volume</td>
<td>5</td>
<td>1.45</td>
</tr>
</tbody>
</table>

In order to establish validity and reliability, aforementioned Elliott and Porter presented the test 12 times over 6 years in beginning STEM-related major courses continually reassessing and refining the test based on course outcomes, intending to eliminate student error. In a test for internal consistency, a high-level of internal consistency was found as a whole (Cronbach’s alpha of .920) and within each category (Table 2).

**Table 2: Internal Consistency using Cronbach’s Alpha**

<table>
<thead>
<tr>
<th>Questions</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Questions</td>
<td>0.920</td>
</tr>
<tr>
<td>1 – 4</td>
<td>0.925</td>
</tr>
<tr>
<td>5</td>
<td>0.720</td>
</tr>
<tr>
<td>6 – 12</td>
<td>0.774</td>
</tr>
<tr>
<td>13</td>
<td>0.895</td>
</tr>
<tr>
<td>14 – 17</td>
<td>0.773</td>
</tr>
</tbody>
</table>

*Note: Cronbach’s alpha > .7 was considered acceptable (DeVillis 2003; Kline 2005).

The test was then used as the instrument in this pilot study and given in fall 2014 to 137 eighth grade students and 50 college freshmen students during their regularly scheduled class times. This instrument (given with pencil and paper) was then used to test the researcher’s hypothesis:

**There is a lack of growth in fundamental math skills in students between the eighth grade level and college freshmen level.**

Using SPSS for data analysis, independent t-tests, using a between-subjects design, on the total scores as well as on the individual categories were run to test the hypothesis. A Mann U Whitney Test was then run to confirm the results of the t-test findings. The pilot study purposely
did not collect demographic information on any of the students. The researchers recognize the possible significance of this information and with the successful finding of the “lack of growth” will add this demographic information to future studies.

Specifically, the individual questions on the exam pertained to the following categories. The complete example of the exam may be found in the appendix.

**Findings**

An independent-samples t-test was used to test between-groups for eighth grade and college freshman students with a dependent variable of math skills and independent variable of educational level. The null hypothesis for all independent-samples t-test was:

\[ H_0: \text{sample means of the two groups are equal} \ (\mu_{8\text{th-grade}} = \mu_{\text{college-freshman}}) \]

\[ H_A: \text{sample means of the two groups are not equal} \ (\mu_{8\text{th-grade}} \neq \mu_{\text{college-freshman}}) \]

With the unequal populations, t-test assumptions did often fail homogeneity of variance, as noted. Although Norman (2010) states that the t-test can still be used with valid results, the Mann U Whitney test was performed to confirm and offer more insight into the t-test results. In this case, the hypothesis was:

\[ H_0: \text{medians (or distributions) of the two groups are equal} \ (M_{8\text{th-grade}} = M_{\text{college-freshman}}) \]

\[ H_A: \text{medians (or distributions) of the two groups are not equal} \ (M_{8\text{th-grade}} \neq M_{\text{college-freshman}}) \]

**Test 1: Independent-samples t-test on totals**

The first independent-samples t-test explored the differences in total scores on the math test given to 8th graders (n = 137) and college freshman (n = 50) entering a STEM-related field. Examination of the boxplot showed no outliers and total scores were found to be normally distributed for the 8th grade class with a skewness of -.514 (SE = .207) and kurtosis of -.769 (SE = .411) and for college freshman a skewness of -.419 (SE = .337) and kurtosis of -.380 (SE = .662). Although there was not homogeneity of variances, as assessed by Levene’s test for equality of variances (p = .0005), the distributions were similar. As a whole, the college freshman performed better (M=24.32, SD=5.02) on the math skills test than did the 8th graders (M=20.69, SD=8.58), a statistically significant difference, M = 3.63, 95% CI [1.62 to 5.65], t(148.466) = 3.563, p = .0005. Since there was a statistically significant difference between means (p = .0005), we reject the null hypothesis and accept the alternative.

Since there was no homogeneity of variance, which is to be expected on unequal populations, the Mann U Whitney test was performed to support the decision to reject the null. Distributions of math skill scores were similar, as assessed by visual inspection. Median math scores were statistically higher in college freshman (Mdn = 25.5) than 8th graders (Mdn = 22), U = 4133.5, z = 2.165, p = .030. The Mann U Whitney test supported the rejection of the null hypothesis and acceptance of alternative.

**Test 1 conclusion:** University freshmen performed better overall than did eighth graders.

**Test 2: Independent-samples t-test on fraction conversion category**

The next five tests examine the differences between groups in the individual categories listed in Table 1. This first categorical between groups (8th graders, n = 137 and college freshman, n = 50) t-test examined differences in math skills in the fraction conversion category between 8th graders and college freshman entering a STEM-related field. In this category, the data was not normally distributed for either the 8th graders or college freshman. However, upon visual examination of both the Normal Q-Q plots and histograms, the data for both groups reflected similarly and was found to be extremely, negatively skewed. No outliers
were noted on the boxplot. The scores for this category were noted for 8th graders with a strong negative skewness of -.727 (SE = .207) and acceptable kurtosis of -.929 (SE = .411) and for college freshman, again, a strong negative skewness of -.994 (SE = .337) and acceptable kurtosis of -.151 (SE = .662). There was not homogeneity of variances, as assessed by Levene’s test for equality of variances (p = .0005). Even though the data reflected heavy-tailedness, the t-test is still considered a robust method for testing (Norman, 2010). Using the Welch t-test, the college freshman performed slightly better (M=12.84, SD=3.36) in the math skills fraction conversion category than did 8th graders (M=11.08, SD=5.20), a statistically significant difference, M=1.76, 95% CI [0.473 to 3.047], t(134.669) = 2.704, p=.008. As such, there was a statistically significant difference between means (p = .008), and therefore, we can reject the null hypothesis and accept the alternative.

Due to the large variance, strongly skewed distribution and heterogeneity of variance, which Wilcoxon (2012) suggests may result in a Type II error on a t-test, a Mann-Whitney U test was run in conjunction. Visually, distributions of the fraction conversion math skills category scores were similar. Visually inspecting Q-Q plot shows the same extreme, negative skewness both (8th grade = -.351; college freshman = -2.94). However, median math skills scores were not statistically significant between college freshman (Mdn = 14) and 8th graders (Mdn = 13), U = 3885.0, z = 1.423, p = .155. This would appear to more accurately reflect the central tendency of the population sample in this category because in a heavily skewed distribution, the median can often serve as a better predictor than the mean. In this case, the null hypothesis is accepted, which is opposite from the t-test results.

Test 2 conclusion: There was no growth shown between eighth graders and university freshmen.
significant difference, $M=1.01$, 95% CI [0.714 to 1.308], $t(146.193) = 6.723$, $p=.0005$. In this test, there was a statistically significant difference between means ($p = .0005$), and therefore, we can reject the null hypothesis and accept the alternative hypothesis.

Due to the strongly skewed distribution and heterogeneity of variance, a Mann-Whitney U test was run in conjunction to the t-test. Visually, distributions of the fraction conversion math skills category scores were similar. Median scores in this category were statistically higher in college freshman ($Mdn = 5.0$) than 8th graders ($Mdn = 3.0$), $U = 4677.0$, $z = 4.972$, $p = .0005$. Null hypothesis is rejected and alternative hypothesis is accepted supporting the results found in the t-test.

Test 3 conclusion: University freshmen performed slightly better than eighth graders.

**Figure 2: Independent-samples t-test on ruler measurement category**

Test 4: Independent-samples t-test on simple area & volume category

The fourth categorical t-test between groups (8th graders, $n = 137$ and college freshman, $n = 50$) was run to determine if there were differences in math skills in the simple area and volume category. When examining this category, the data was normally distributed. No outliers were noted on the boxplot. The scores for this category were noted for 8th graders with a skewness of .458 (SE = .207) and kurtosis of -1.038 (SE = .411) and for college freshman, again, a skewness of .513 (SE = .337) and kurtosis of -.696 (SE = .662). There was not homogeneity of variances, as assessed by Levene’s test for equality of variances ($p = .027$). Using the Welch t-test, the college freshman performed at almost the same level ($M=3.18$, $SD=1.85$) in the math skills simple area and volume category as did 8th graders ($M=2.86$, $SD=2.29$). This was not a statistically significant difference, $M=0.319$, 95% CI [-0.328 to 0.965], $t(106.950) = 0.977$, $p=.331$. There was not a statistically significant difference between means; therefore, the null hypothesis is accepted.

Due to heterogeneity of variance, a Mann-Whitney U test was run in conjunction. Visually, distributions of the simple area and volume math skills category scores varied slightly. Median scores in this category were very similar in college freshman ($Mdn = 3.0$) to 8th graders ($Mdn = 2.0$), $U = 3859.0$, $z = 1.340$, $p = .180$ where mean ranks showed 8th graders (90.83) and college freshman (102.68). Null hypothesis was accepted supporting the results found in the t-test.

Test 4 conclusion: There was no growth between eighth graders and university freshmen.
Test 5: Independent-samples t-test on probabilities & averages category

The fifth categorical t-test between groups (8th graders, n = 137 and college freshman, n = 50) was performed to determine if there were differences in the probabilities and averages category. When examining this category, the data was not normally distributed for both the 8th graders and college freshman. However, a visual examination of the distributions through Q-Q plot and box plot showed very similar distributions. Although 4 outliers appeared on the college freshman boxplot, they were included in the measurements as they were not extreme enough to warrant exclusion. The scores for this category were noted for 8th graders with a heavy negative skewness of -.654 (SE = .207) and kurtosis of -1.379 (SE = .411) and for college freshman, again, a heavy negative skewness of -1.654 (SE = .337) and kurtosis of 5.090 (SE = .688). There was not homogeneity of variances, as assessed by Levene’s test for equality of variances (p = .001). Using the Welch t-test, the college freshman performed slightly above (M=2.42, SD=1.07) the 8th graders (M=1.95, SD=1.30) in the math skills probability and averages category with a statistically significant difference, M=0.323, 95% CI [0.099 to 0.844], t(105.144) = 2.507, p=.014. There was a statistically significant difference between means (p = .014), and therefore, we can reject the null hypothesis and accept the alternative.

In the t-test, heterogeneity of variance was noted as well as negative skewness. Another item worth noting is the kurtosis was outside of the normalized range, but this was to be expected due to all the 0 answers as noted on Figure 4. Due to these violations, a Mann-Whitney U test was run in conjunction. Visually, distributions of the probability and averages category scores were very similar. Median scores in this category appeared equal in college freshman (Mdn = 3.0) and 8th graders (Mdn = 3.0). However, Mann U = 4073.5, z = 2.247, p = .025 shows a statistical significance between mean ranks of the distributions for college freshman (mean rank = 106.97) and 8th graders (mean rank = 89.27). Null hypothesis is rejected and alternative hypothesis is accepted supporting the results found in the t-test.

Test 5 conclusion: University freshmen performed slightly better than eighth graders.
Test 6: Independent-samples t-test on complex area and volume category

The final categorical t-test between groups (8th graders, n = 137 and college freshman, n = 50) was completed to determine if there were differences in the complex area and volume category. When examining this category, the data was not normally distributed for both the 8th graders and college freshman. However, a visual examination of the distributions through Q-Q plot and box plot showed very similar distributions. Two outliers were shown in each group on the boxplot, but were not extreme enough to warrant exclusion. The scores for this category were noted for 8th graders with a slightly positive skewness of .356 (SE = .207) and kurtosis of .924 (SE = .411) and for college freshman, again, a slightly positive skewness of 1.008 (SE = .337) and kurtosis of 2.554 (SE = .662). There was homogeneity of variances, as assessed by Levene’s test for equality of variances (p = .588). The college freshman performed at the same level (M=1.68, SD=.94) as the 8th graders (M=1.37, SD=.92) in the math skills complex area and volume category. There was not a statistically significant difference, M=0.307, 95% CI [0.007 to 0.608], t(185) = 2.002, p=.05; therefore, we accept the null hypothesis that the means are equal.

Due to positive skewness, a Mann-Whitney U test was run in conjunction. Visually, distributions of the complex area and volume category scores were very similar. Median scores in this category showed college freshman (Mdn = 2.0) as higher than 8th graders (Mdn = 1.0). Mann U = 3960.5, z = 1.745, p = .081 also shows a statistical significance between medians. In this case, the null hypothesis was accepted supporting the results found in the t-test.

Test 6 conclusion: There was no growth between eighth graders and university freshmen.

Table 2: Summary of Final Results for Each Category for this Pilot Study

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>T-TEST</th>
<th>MANN U WHITNEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals</td>
<td>College Freshman</td>
<td>College Freshman</td>
</tr>
<tr>
<td>Fraction Conversion</td>
<td>College Freshman</td>
<td>Equal – No growth</td>
</tr>
<tr>
<td>Ruler Measurement</td>
<td>College Freshman</td>
<td>College Freshman</td>
</tr>
<tr>
<td>Simple Area and Volume</td>
<td>Equal – No growth</td>
<td>Equal – No growth</td>
</tr>
<tr>
<td>Probability and Averages</td>
<td>College Freshman</td>
<td>College Freshman</td>
</tr>
<tr>
<td>Complex Area and Volume</td>
<td>Equal – No growth</td>
<td>Equal – No growth</td>
</tr>
</tbody>
</table>

*Note: p < .05. If a group is listed (i.e. College Freshman or 8th grade), then this group was significantly higher than the other group (H0 rejected). If Equal is listed, both groups did not have a significant difference (H0 accepted).
Conclusions and Recommendations

The results of the pilot study confirmed the literature review findings. In three of the five categories there was no growth between eighth grade and university freshmen level students in mathematics. This suggests the need for a broader, more in-depth analysis of mathematics education at the K-12 level and its direct relationships with students’ desires to enter STEM fields. While college freshmen showed a small statistical improvement in some areas tested, the growth in mathematics during the high school years that would be expected was not found. Understanding the significant drop in young peoples’ desire to enter the STEM field, this apparent lack of basic math knowledge cannot be ignored as a possible deterrent.

During the high school years, many students are allowed to select the courses in which they enroll. Math skills, like many other skills, improve with repetitive practice. High school math curriculum, while designed to be flexible, has the potential negative effect of allowing students to continue multiple semesters and possibly years without a mathematics course. When students take college placement exams and/or a math course and underperform, they then begin to seek career paths that do not require advanced math skills. The pilot study conducted leads one to ask whether or not students have lost the cognitive ability to complete math problems, and whether the students’ overall lack of practice has affected their math performance including confidence in their math skills. As educators within STEM-related fields, it is our duty to collaborate with K-12 education to insure that this math confidence is not only maintained, but grown by ensuring students are exposed to opportunities to gain new math skills throughout their high school career.

The pilot study provided valuable information regarding the lack of growth in math skills possibly occurring during high school. When expanding the study to a larger sample in order to provide generalizable results, important demographic information should be collected. For example, more data between groups for both middle school and college students pertaining to: gender, math confidence levels, guardian education level, and household income could provide greater insight. Specifically at the middle school level, students’ current interest in STEM fields and their past mathematics scores should be collected to better gauge when the math gap is occurring. The timing of the exam at the middle school level should also be coordinated with the teachers to be administered toward the end of the eighth grade year. This ensures that the researchers are measuring the students after all concepts have been taught. At the college level, the short exam should be given within the first few weeks of the fall semester to again insure the data collected is pulling directly from the high school experience. Gathering information pertaining to their high school experience such as college entrance exam scores, block scheduling or traditional scheduling, and length of time since their last math course would also be of interest. Expanding the study to both STEM and non-STEM majors within the college participant list would also add an interesting control group component to better understand the math gap as related to STEM fields.

The shortage of young people entering STEM fields is concerning. While there is no simple or single answer to solve this problem, the research presented in the pilot study confirms and expands the findings of previous researchers. The use of math skills will always be a necessity regarding career fields in the STEM arena. Uniquely, this pilot study disregards the more advanced mathematic training and looks at what should be considered as foundational math skills. When the results of the study show little or no growth during the high school years, the confidence level and drive of the younger generation to enter fields where mathematics is a known tool is hindered. Future studies...
that collect the expanded demographic information and deepens the data pool will continue to allow researchers to address this lack of growth. This then allows K-12 curriculum development to focus on a steady maintenance schedule to ensure solid math skills upon entrance and exit from high school.

REFERENCES


Appendix

Construction Math and Measurement

When constructing houses or other buildings, it is often necessary to convert fractions to decimals. This practice is most common when inches are converted to decimal feet. An example would be when 12” (twelve inches) becomes 1.0’ (one decimal foot). You may use a calculator for this assignment.

1. Convert the following Measurements to Decimal Feet (round to two decimal places when necessary):
   - 5” ___________  
   - 9” ___________  
   - 6” ___________  
   - 10” ___________  
   - 3” ___________  
   - 7” ___________  

2. For the following fractions, what is one-half their value? (Answer in fractions and reduce)
   - ¾” ___________  
   - ½” ___________  
   - 7/8” ___________  

3. For the following fractions, what is twice their value? (Answer in fractions and reduce; convert to mixed number when possible)
   - 5/16” ___________  
   - 3/32” ___________  
   - 9/16” ___________  

4. Complete the following problems (convert to mixed number when possible):
   a. 5/16 + 3/8 + 11/32 =
   b. 13/16 – 3/8 =
   c. 1.23 x 5 =
   d. 12.64 / 4 =

5. Correctly indicate the measurements shown on the tape measurer below:
   - A. ______
   - B. ______
   - C. ______
   - D. ______
   - E. ______
6. How many square feet (SF) equal one square yard (SY)? _______________________________

7. One cubic foot (CF) equals _______ x _______ x _______

8. How many cubic feet (CF) equal one cubic yard (CY)? ____________________________

9. Express the following geometric shapes using the following units:

   Feet only, no inches 2’

   4.5’

   ______ SF (square feet)
   ______ SY (square yard)

10. 3.75’ 22” 4.66’

    ______ SF (square feet)

11. H = 69”
    B = 14.25’

    ______ SF (square feet)

12. H = 1’
    B = 41”

    ______ SF (square feet)
13. Find the average of the following series of numbers:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>10</td>
<td>100</td>
<td>1,000</td>
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<tr>
<td>15</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>20</td>
<td>250</td>
<td>1,500</td>
</tr>
<tr>
<td>14</td>
<td>50</td>
<td>14</td>
</tr>
<tr>
<td>25</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

14. Find the area for the following geometric shape?

Area = ________________ SF
15. Find the hypotenuse side of the right triangle:

\[ h = \sqrt{9^2 + 12^2} \]

16. Assuming a cube measures 4’ x 4’ x 4’, express the volume in the following units:

\[ \text{Volume in CF (cubic feet)} \]

\[ \text{Volume in CY (cubic yard)} \]

17. Find the volume of the cylinder.

\[ R = 30” \]
\[ H = 6’ \]

\[ \text{Volume in CY (cubic yards)} \]
How U.S. Universities Intend to Meet Their Carbon Neutral Goals

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ABSTRACT

Universities have been on the leading edge for implementation of sustainable practices, green building certification, and the push to limit emission of greenhouse gases. In 2006 leadership at twelve universities was instrumental in the creation of the American College & University Presidents’ Climate Commitment (ACUPCC). The two overall goals of the ACUPCC were to gain university commitment to eliminate greenhouse gas emissions from their campus operations and to promote sustainability education and research. A decade later there are over 650 that have officially pledged their support to the ACUPCC and in doing so have established a goal toward carbon neutrality for their university. This study examines university carbon neutrality objectives and the strategies being employed to reach their carbon neutral goals. The population for this research effort is universities that are signatory to the ACUPCC. The findings are that university carbon neutral objectives are typically almost three decades into the future. Mitigation strategies to reduce energy use and lower greenhouse gas emissions typically have low initial investment requirements and relatively quick payback. The focus of mitigation strategies includes new facilities, renovated, and exiting building stock on campus. To reach their carbon neutrality objectives the university’s energy source(s) will shift from fossil fuels to renewables. In addition, Universities do not intend to rely on carbon offsets to reach their carbon neutral objectives.

Key Words: carbon neutral goals, carbon neutrality, ACUPCC, sustainability, greenhouse gases

Authors

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INTRODUCTION

The majority of the American populace is concerned about climate change. In a recent Gallup poll fifty-eight percent (58%) of Americans ‘worry a great deal or a fair amount about global warming’ and a majority say the effects of warming are already evident (Saad 2013). NASA also submits that climate change is having ‘observable effects on the environment’ (NASA 2016).

In an effort to lend support to avert the dangers of climate change the U.S. Environmental Protection Agency has adopted a primary focus directed toward reducing greenhouse gas emissions. The agency submits that “cleaning up carbon pollution protects our environment and supports a strong, clean-energy economy” (EPA 2014). The Intergovernmental Panel on Climate Change (IPCC) claims that a major reduction in greenhouse gas emissions is essential to avoid the catastrophic effects of climate change. IPCC) is an international body established in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) to assist in the assessment of scientific data related to climate change (Thompson 2014). IPCC’s recent report, Climate Change 2014: Impacts, Adaptation and Vulnerability, calls for a 40%-70% reduction in greenhouse gas emissions by 2050 to stem the disastrous effects of rising global temperatures (IPCC 2014).

Worldwide, most all of the greenhouse gas emissions are caused by human activity. The main human activity that emits CO2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation, although certain industrial processes and land-use changes also emit CO2. In 2014, the share of emissions caused by human activities in the U.S. was greater than eighty percent. Consistently, the main contributor has been the combustion of fossil fuels for transportation and generation of electricity. Combined they produce sixty-eight percent (68%) of the carbon dioxide emissions in the United States.

Figure 1: U.S. Carbon Dioxide Emissions

US Environmental Protection Agency

Other (Non-Fossil Fuel Combustion) 6%
Residential & Commercial 10%
Industry 15%
Transportation 31%
Electricity 37%

(Figure 1: EPA 2014).

A significant portion of the emissions for electrical power generation is to heat, cool, and light the homes that people live in and the buildings in which they work. The U.S. Green Building Council (USGBC) submits that buildings account for thirty-eight percent (38%) of all CO2 emissions (USGBC 2016).

Over the past decade, concern regarding greenhouse gas emissions and climate change has heightened. Increasingly businesses, institutions, and individuals have taken actions to reduce carbon emissions and move toward carbon neutrality for themselves and their...
organizations. Universities (and colleges) have been at the forefront of the trend toward sustainable initiatives and have one of the highest concentrations of green buildings (USGBC 2016, Martin et al 2012, Dougherty 2010).

In October 2006 twelve university and college presidents, along with Association for the Advancement of Sustainability in Higher Education (AASHE), initiated action to gain support of higher education institutions to address global warming. The founding presidents believed that higher education had the capacity and responsibility to lead climate and sustainability action. In support of that objective the founders created the American College & University Presidents’ Climate Commitment (ACUPCC). The ACUPCC had two primary goals: 1) gain institutional commitment to eliminate greenhouse gas emissions from campus operations and 2) promote sustainability education and research (Frank 2010).

Subsequent to establishing ACUPCC, presidents from the twelve founding universities initiated action to encourage their peer institutions across the nation to become signatory to ACUPCC. Approximately ten years later there are over 650 institutions that have officially pledged their support to the ACUPCC. Most of the universities and colleges signatory to ACUPCC are also affiliated with Second Nature, a support organization for the ACUPCC (Second Nature 2016).

A primary concern of ACUPCC is a reduction of the greenhouse gas carbon dioxide. The ultimate objective is carbon neutrality for each institution signatory to the agreement. Carbon neutrality, or having a zero carbon footprint, is normally achieved by developing an action plan to: a) reduce/change activities or systems to reduce emissions, and b) shift energy use from fossil fuels to renewables. An institutional plan to reach carbon neutrality is commonly referred to as a Climate Action Plan (CAP). Institutions signatory to ACUPCC are required to develop a CAP within two years of signing the commitment (ACUPCC).

The Association for the Advancement of Sustainability in Higher Education (AASHE), has detailed the necessity of a CAP and why all carbon neutral seeking institutions should develop one. One key reason is to generate an understanding of the problem of global climate change and reinforce the institution’s desire to seek solutions. Another is to create an awareness that Green House Gas (GHG) emissions reductions can have substantial value in, a) reducing operating costs, b) attracting students, faculty, and funding, c) increasing productivity, and d) improving public relations. A Climate Action Plan gives the university a better understanding of the scope of the challenge and an opportunity to define goals, strategies, and tactics to achieve carbon neutrality. A portion of the Climate Action Plan generally involves a plan to shift the institutions energy source to renewables. (Simpson 2009). Climate Action Plans clearly define goals, communicate a baseline emissions level, and make preliminary plans for progress toward carbon neutrality (Turner 2013).

A research effort in 2015 investigated green initiatives on university campuses across the U.S. (Bausman and Mueller 2015). This study examined green initiatives, including efforts to reduce carbon emissions that universities incorporated in new construction and renovation of their existing building inventory on campus. The findings were that university focus for green initiatives was primarily on new construction and not the ‘greening’ of existing building stock. Forty-three percent (43%) of the universities participating in the study had made a commitment to become carbon neutral. However this same study found that “for a vast majority of the institutions
(82%) the use of renewable sources for onsite energy production met less than 20% of the university's needs" (p34). An additional key finding was that "universities are committed to green building practices that reduce energy and water consumption, but seldom support solar or geothermal initiatives …" (Bausman and Mueller 2015, p34).

This study's finding that the focus of university green initiatives was primarily on new construction, which seldom included solar or geo-thermal energy, raises the question. How do universities intend to meet their carbon neutral goal without a strong focus on their existing building stock combined with a significant shift toward renewable energy?

**STUDY OBJECTIVE**

This study investigated the actions that colleges and universities across the United States are taking to achieve carbon neutrality. Specifically, this research effort examined the green initiatives universities and colleges are implementing on new and existing building stock and the actions they are taking to reduce their carbon footprint.

**Methodolgy**

**Population and Sample Selection**

The population selected for this study was facility managers or sustainability champions at Universities and Colleges in the US that have made a commitment to carbon neutrality – to neutralize their greenhouse gas emissions. Many of the institutions that have made a carbon neutral commitment include those that are signatory to the ‘American College & University Presidents’ Climate Commitment’ (ACUPCC).

The sampling frame used for this study was provided by ‘Second Nature’. Second Nature, with assistance provided by AASHE, is the main supporting organization for the ACUPCC.

Second Nature maintains a database of institutions along with their Commitment, Greenhouse Gas Reports, Climate Action Plan, and progress reports. Second Nature provides sustainability planning and climate action guidance for leadership in universities across the nation (Secondnature.org). At the time of this study, there were six hundred seventy-five (675) reporting institutions in Second Nature’s database. Out of this total, 638 of these institutions had made a commitment toward ‘carbon neutrality’. From this database of 638 colleges and universities, 250 institutions were randomly selected to create the sample used for this study.

**Survey Questionnaire**

A detailed questionnaire containing 49 questions was developed and distributed to the selected sample. The questionnaire was subdivided into 5 sections. The first section of the questionnaire involved general questions such as university name, type (public or private), carbon neutral date and whether or not the University was ACUPCC signatory.

The second section contained twenty questions (20) concerning mitigation strategies that the university was implementing on new and existing buildings to reach its carbon neutral goals. Mitigation strategies for carbon neutrality typically include three general approaches: a) avoiding or reducing emissions; b) eliminating emissions by switching to renewable (zero carbon) sources of energy, and c) offsetting emissions. The questions in this section asked how frequently each mitigation strategy was incorporated in their new and existing buildings. The next section included questions that targeted the university’s energy requirements for their current and future needs. Primary energy sources take many forms, including nuclear energy, fossil energy (oil, coal and natural gas) and renewable sources like wind, solar and hydropower. These primary sources are converted to electricity (secondary
source) which flows through power lines and other transmission infrastructure to University facilities. The questions in this section asked what percentage of the University’s energy needs, were currently and anticipated to be met by each energy source. The fourth section of the questionnaire involved questions related to sustainable transportation solutions and the final section addressed the general mindset of the university towards Carbon offsets.

Data Analysis
The general information collected in the first section of the questionnaire provided nominal data. Survey questions in the remaining four sections were typically structured to provide interval data by incorporating a 5-point Likert scale.

Survey responses were subjected to statistical means testing using a confidence level of 95%. In addition, t-tests with an $\sigma = .05$ (assuming unequal variances) were conducted between various respondent groups.

FINDINGS AND ANALYSIS

Survey Response
The Survey was made available online and hardcopies were sent to the randomly selected sample of 250 Universities. Responses were received from 66 institutions out of the selected sample for a response rate of 26.4%.

University Status and Carbon Neutral Goal
Of the sixty-six (66) institutions completing the questionnaire, forty-two (64%) were public universities or colleges. The remaining twenty-four respondents (34%) were private institutions. All of the sixty-six survey respondents are ACUPCC signatories and have Carbon Neutral goals.

Only forty-four (67%) of the responding universities had established a date to reach their carbon neutral goal. Goals established by these universities ranged from the year 2018 to 2075. Figure 2: Carbon Neutral Goal provides the distribution of the respondents. Less than 10% expected to reach carbon neutrality by 2020 and almost half of the universities had established a carbon neutral goal of 2050. The average carbon neutrality goal was 2043, or approximately twenty-seven years into the future.

Mitigation Strategies
The section of the questionnaire that investigated mitigation strategies employed by the university contained two parts – both of which were structured to address the research question of “what the university was currently doing to achieve their Carbon Neutral goal”. The first section involved thirteen (13) strategies that could be incorporated in new or substantially renovated buildings on campus and the second part addressed seven (7) strategies that could be incorporated into existing buildings. The response options for each question ranged from none to all buildings with $1 = \text{None}, 2 = \text{Few}, 3 = \text{Some}, 4 = \text{Most},$ and $5 = \text{All Buildings}$. 

Mitigation Strategies for New or Substantially Renovated Buildings
The questions and corresponding mean responses for mitigation strategies used in new or substantially renovated buildings is shown in Table 1. The most commonly employed strategies were high efficiency lighting, temperature controls, occupancy sensors, and high performance windows. A majority of
universities (56%) incorporated high efficiency lighting in all of their buildings and 96% of the respondents used high efficiency lighting in most or all of their new (or substantially renovated) facilities. Similarly, seventy-five percent (75%) or more of the respondents incorporated temperature controls, high performance windows, and occupancy sensors in most or all of their new buildings.

Table 1

<table>
<thead>
<tr>
<th>MITIGATION STRATEGY</th>
<th>Mean Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>High efficiency fixtures/lamps</td>
<td>4.53</td>
</tr>
<tr>
<td>Establishing temperature controls to reduce energy</td>
<td>4.25</td>
</tr>
<tr>
<td>consumption</td>
<td></td>
</tr>
<tr>
<td>Occupancy sensors to control lighting</td>
<td>4.22</td>
</tr>
<tr>
<td>High performance windows</td>
<td>4.17</td>
</tr>
<tr>
<td>Increased thermal resistance of the exterior envelope</td>
<td>3.85</td>
</tr>
<tr>
<td>Energy Management System to automatically adjust</td>
<td>3.71</td>
</tr>
<tr>
<td>heating and cooling</td>
<td></td>
</tr>
<tr>
<td>Detailed monitoring of energy use by building</td>
<td>3.67</td>
</tr>
<tr>
<td>systems</td>
<td></td>
</tr>
<tr>
<td>Building orientation to enhance daylighting</td>
<td>3.33</td>
</tr>
<tr>
<td>Cool Roofs - roofs with heat-reflective materials</td>
<td>3.07</td>
</tr>
<tr>
<td>Increase task lighting to decrease general illumination</td>
<td>2.91</td>
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<td>Incorporating passive heating and cooling</td>
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<td>Skylights to enhance daylighting</td>
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<tr>
<td>Green Roof</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Strategies less often employed were increased thermal resistance, energy management systems, energy monitoring, and building orientation to enhance daylighting. Almost two-thirds (66%) of the universities increased the thermal resistance of the exterior envelope and approximately sixty percent (60%) incorporated energy management systems, building orientation, and energy monitoring on most or all of their new facilities.

Table 1

Very few of the universities supported installation of green roofs. Sixty percent (60%) of the respondents did not install a green roof on any of their buildings and 25% installed green roofs on only a few of their new facilities. Skylights to enhance daylighting were more common. However, they were employed on most or all new buildings by only 25% of the universities while almost half (49%) utilized skylights on few or none of their buildings. Similarly, close to half of the respondents (47%) incorporated passive heating and cooling on few or none of their new (or substantially renovated) facilities.

To determine if the carbon neutral goal had an impact on strategy, a statistical analysis was performed by grouping the respondents based on their carbon neutral date. The respondents were divided into two groups. The first group contained universities with a carbon neutral objective prior to 2050 and the second grouping had a carbon neutral date of 2050 or later. A one tailed t-test was performed and there was a statistically significant difference for two mitigation strategies. Universities with a carbon neutral goal prior to 2050 were more likely to increase the thermal resistance of the exterior envelope and increase task lighting to decrease general lighting.

Private and public universities were also comparatively analyzed to determine if there were any strategy differences. The findings were that there was no statistically significant difference between private and public universities regarding the 13 strategies investigated in this section of the questionnaire.
Mitigation Strategies in Existing Buildings
The second part of this section investigated mitigation strategies that universities used in existing building stock on campus. Seven strategies were examined. They included the use of cool roofs, high efficiency fixtures and lamps, occupancy sensors, energy efficient HVAC equipment, temperature controls, and energy management systems. Figure 3 depicts the percentage of institutions that incorporated each strategy in all and most of their existing buildings on campus. The most widely accepted strategies are the use of high efficiency lamps and lighting fixtures which were installed in most or all of the buildings for approximately three quarters of the respondents (75% and 73% respectively). Approximately two thirds (66%) installed temperature controls and more than half incorporated energy efficient HVAC equipment (58%), occupancy sensors (56%), and energy management systems (58%) in most or all of their existing building stock. The only approach that was sparingly applied was cool roofs.

Again, to determine if the carbon neutral goal had an impact on strategy, a statistical analysis was performed by grouping the respondents based on their carbon neutral date. The first group contained universities with a carbon neutrality objective prior to 2050 and the second grouping had a carbon neutral date of 2050 or later. A one tailed t-test was performed and there was a statistically significant difference for four of the seven mitigation strategies. Universities with a carbon neutral goal prior to 2050 were more likely to replace existing lighting with high efficiency fixtures, change HVAC equipment to high efficiency models, incorporate energy management systems, and replace existing roofs with cool roofs.

Private and public universities were also comparatively analyzed to determine if there were any strategy differences. The findings were that public universities are more likely to change HVAC equipment to high efficiency models, incorporate energy management systems, and replace existing roofs with cool roofs on their existing building stock on campus.

Energy Technologies on Campus
The next portion of the questionnaire asked the respondents what portion of their university’s current and anticipated future energy needs would be met by each of five primary energy sources – coal, fuel oil, natural gas, nuclear energy, and renewable energy.

Current Energy Sources
Table 2: Current Energy Sources tabulates the current level of energy use for each primary energy source. The level of reliance for an energy source (Percentage of Current Energy Need) was divided into five response categories ranging from 0-20% to 80-100%. The percentage of universities indicating their level of reliance on each energy source to meet their current energy needs is tabulated in the lower portion of the table. For
example, 33% of the universities currently rely on coal to meet 0-20% of their energy needs and 26% of universities rely on coal for 21-40% of their needs.

The distributions for all five energy sources were statistically analyzed and the two most common energy sources used to meet current needs are coal and natural gas. Approximately forty percent (40%) of the universities participating in this study indicated that they relied on coal and/or natural gas for 41-100% of their current energy needs. Conversely, only 13% had this level of reliance on renewables and it was even less for nuclear and fuel oil.

### Table 2: Current Energy Sources

<table>
<thead>
<tr>
<th>Percentage of Current Energy Need</th>
<th>0-20%</th>
<th>21-40%</th>
<th>41-60%</th>
<th>61-80%</th>
<th>81-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>33%</td>
<td>26%</td>
<td>25%</td>
<td>9%</td>
<td>7%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>80%</td>
<td>9%</td>
<td>8%</td>
<td>3%</td>
<td>---</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>22%</td>
<td>38%</td>
<td>25%</td>
<td>13%</td>
<td>2%</td>
</tr>
<tr>
<td>Nuclear Energy</td>
<td>70%</td>
<td>21%</td>
<td>6%</td>
<td>3%</td>
<td>---</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>67%</td>
<td>20%</td>
<td>3%</td>
<td>5%</td>
<td>5%</td>
</tr>
</tbody>
</table>

### Future Energy Sources

The respondents were then asked to predict their reliance on these same five primary energy sources in the future that would be necessary to support their organization’s carbon neutral commitment. Table 3: Future Energy Sources tabulates their input.

The distributions for all five energy sources were statistically analyzed and the most common energy source anticipated to meet future demand was renewable energy. In addition, a statistical comparison of the response distributions for both current and future needs found that university reliance on natural gas and nuclear energy for their future energy needs statistically remained unchanged. However, the analysis highlighted a reduction in the use of coal and fuel oil and an increase in the use of renewable energy. Seventy-seven percent (77%) of universities anticipate that renewable energy sources will need to meet 41% or more of their energy demands when they reach their carbon neutral goal.
Table 3: Future Energy Sources
Percentage of Current Energy Need

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>% of Universities Reliance on Each Energy Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-20%</td>
</tr>
<tr>
<td>Coal</td>
<td>81%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>96%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>35%</td>
</tr>
<tr>
<td>Nuclear Energy</td>
<td>72%</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 4: Change in Energy Source shows just how dramatic the anticipated shift in energy reliance is forecast to be by the universities participating in this study. Ninety-two percent (92%) of the universities forecast an increased reliance on renewable energy. Conversely, seventy percent (70%) of the respondents forecast a decrease in the use of coal and half (50%) indicated a reduction in their reliance on natural gas. Utilization of nuclear and fuel oil are forecast to be more stable but their level of use, both currently and forecast, remains low.

Table 4: Change in Energy Source

<table>
<thead>
<tr>
<th>Anticipated Change</th>
<th>Coal</th>
<th>Fuel Oil</th>
<th>Natural Gas</th>
<th>Nuclear</th>
<th>Renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Use</td>
<td>2%</td>
<td>3%</td>
<td>10%</td>
<td>11%</td>
<td>92%</td>
</tr>
<tr>
<td>Decrease Use</td>
<td>70%</td>
<td>36%</td>
<td>50%</td>
<td>22%</td>
<td>---</td>
</tr>
<tr>
<td>No Change</td>
<td>28%</td>
<td>61%</td>
<td>40%</td>
<td>67%</td>
<td>8%</td>
</tr>
</tbody>
</table>
To determine if the carbon neutral goal had an impact on energy source, a statistical analysis was performed by grouping the respondents based on their carbon neutral date. Similar to prior testing, universities with a carbon neutrality objective prior to 2050 were compared to those with a carbon neutral date of 2050 or later. The findings were that there was no statistically significant difference between universities that had carbon neutral date prior to 2050 versus those with a date after 2050 regarding the source for both current energy needs and anticipated future energy needs. Similarly when the universities were grouped based on university type (private or public), there was no statistically significant difference between private and public universities regarding the source for current energy needs or anticipated future energy needs.

Renewable Energy Source(s)
The next section asked the respondents how important each of five renewable and low emission energy sources were to meet their carbon neutral goal. The energy sources investigated included solar, wind, geo-thermal, bio mass, fuel cell, and hydro-electric. Response options ranged from 1 (Unimportant) to 5 (Extremely Important). Figure 4: Sustainable Energy Sources displays the mean response for each of the six energy options.

Solar energy was deemed ‘very important’ for universities in meeting their carbon neutral goal. Two relatively common sustainable energy sources such as wind and geo-thermal were judged ‘somewhat important’ for carbon neutrality. Other sustainable energy sources that had limited importance, as viewed by the institutions in this study, were hydro-electric, bio mass and fuel cell technology.

Sustainable Transportation Solutions
Transportation form and level of use have a significant impact on university energy needs and their carbon footprint. As a result, survey participants were asked to identify the importance of various sustainable transportation solutions to reduce energy consumption. Sustainable solutions investigated included the use of fuel efficient vehicles, bicycles, public transit, carpooling, and tele-conferencing. Response options ranged from 1 (Unimportant) to 5 (Extremely Important). Figure 5: Sustainable Transportation Solutions displays the mean response for each of the five solutions. Tele-conferencing was deemed the most important, however all of the options were viewed as being moderately important to reach the universities carbon neutral goal.
Carbon Offsets
Another option for carbon neutrality are carbon offsets. With carbon offsets an institution can obtain ‘credit’ from another party for a reduction in greenhouse gas emissions. In essence, the institution is ‘acquiring’ (often purchasing) assistance from an outside party to help reach its carbon neutrality goal.

To assess its use, universities participating in the study were asked what percentage of their carbon neutrality goal would be achieved with carbon offsets. The responses ranged from 0 to 100% with an average of 25.2%. However, almost half (48%) of the universities were planning to utilize carbon offsets for only 10% or less of their goal.

The low use of carbon offsets is reflective of their opinion regarding their use. A statistical analysis of survey responses found that university respondents agree with the following two statements: 1) carbon offsets produce little or no real reduction in greenhouse gases, and 2) carbon offsets are an example of ‘green washing’.

CONCLUSIONS
Carbon Neutrality Objectives are Decades into the Future: Based on the sample used for this study only seventy-one percent (71%) of the signatories of the American College & University Presidents’ Climate Commitment (ACUPCC) have established a carbon neutral date for their institution. Those universities that have established a carbon neutral are typically selecting a date well into the future. Only seven percent (7%) of the respondents are planning to reach carbon neutrality by 2020 while fifty-eight percent (58%) have selected 2050 or beyond. The average objective established for carbon neutrality is almost three decades (27 years) into the future.

Mitigation Strategies are Low Investment/High Reward: Universities are primarily incorporating energy saving techniques that require relatively low initial investment and have a near-term return on their investment. To reach carbon neutral goals universities are incorporating high efficiency lamps & light fixtures, temperature controls, occupancy sensors, high performance windows, and energy management systems on most or all of their buildings – whether it’s a new, substantially renovated, or existing building stock. Conversely, few universities support the installation of green roofs and almost half install skylights to enhance daylighting and incorporate passive heating/cooling on only a few or none of their new facilities.

Universities with a carbon neutral goal prior to 2050 were more likely to replace existing lighting with high efficiency fixtures, change HVAC equipment to high efficiency models, and incorporate energy management systems on new and existing building stock. In addition, public universities were more likely to change HVAC equipment to high efficiency models and incorporate energy management systems on their existing buildings.

Increased thermal resistance of the building envelop and building orientation to enhance daylighting are incorporated on some or most of their new facilities. However, universities with a carbon neutral goal prior to 2050 were more likely to increase the thermal resistance of the exterior envelop and also increase task lighting to decrease general lighting requirements.

Energy Source Shift from Fossil Fuels to Renewables: Currently universities rely heavily on coal and natural gas for their energy needs. As they move toward carbon neutrality they intend to shift from coal and natural gas to
renewables. Seventy percent (70%) of the universities participating in this study expect to reduce their reliance on coal and a majority (50%) forecast a reduction in their dependence on natural gas. Conversely, ninety-two percent (92%) expect to increase their reliance on renewables for their energy needs. The favored renewable energy source is solar, followed by wind and geo-thermal.

Steps taken by most universities to reduce energy requirements for transportation include encouraging tele-conferencing, carpooling, public transit, and bicycling as well as purchasing fuel efficient cars.

Universities Do Not Intend to Rely on Carbon Offsets: Universities intend to reach their carbon neutral objectives by their own actions. They do not favor using carbon offsets to reach carbon neutrality, largely because most believe that carbon offsets are ‘green washing’ and produce little or no real reduction in greenhouse gases.

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USGBC, http://www.usgbc.org/
ABSTRACT

Based on the prediction of US Housing and Urban Development (US HUD), the demand for new homes will increase in the coming months to accompany the steady sales of existing homes. To meet the future demand, the home building industry has to continuously improve and get rid of inherent problems such as frequent delays. While delays have been a common occurrence in the residential and commercial construction alike, investigations of delays in the residential sector has not received much attention. With the goal of exploring the causes of delays in the home building industry, a multiple case study approach was employed in the current study.

Observational data from 30 different home building projects were collected using the Percent Plan Complete (PPC) metric. Detailed data on planned and completed activities from the 30 projects were collected for ten consecutive weeks. Findings reveal that the frequently occurring reasons for delays are related to ‘supplier’, ‘over-assignment’, and ‘no show’. The observed data was stratified to find that the masons, carpenters, and plumbers are the trades most frequently causing delays. The outcome of this study provides helpful guidelines to the home builders for targeting their intervention to reduce delays.

Keywords: Delay, lean, home building, PPC

Authors

Dr. Somik Ghosh is an Assistant Professor at the Haskell and Irene Lemon Construction Science Division at University of Oklahoma. His research interests focus on lean construction and occupational safety.
INTRODUCTION

The national housing market summary published by the US Department of Housing and Urban Development (2014) shows continuous improvement in the sale of single family housing in the fourth quarter of 2014. The improvement in the market is boosted by increase in sales for new homes with a steady sale of existing homes. With the new homes sale showing steady growth along with the overall housing market, the demand for new homes is expected to increase in the coming months. With this demand in sight, each homebuilder seeks to build as many homes as possible within a shorter period of time. The revival of the home building industry has attracted the attention of a number of small contractors, qualified or not so qualified alike. Among them, many contractors have adopted production homebuilding as a model, enabling them to leverage the economy of scale on material procurement as well as getting homes built in larger numbers.

Based on the last census report, there were over 69,000 single family home builders in the US in 2008. The term ‘home builder’ in this context is loosely used to refer to anyone who constructs homes. No distinction is made between large corporations that build hundreds of homes each year and very small builders who may build one or two homes each year. Thus the home building industry is very diverse in terms of business setup and operations. This diversity in the business sizes do not change the construction processes adopted by the home builders. The home building industry in North America has managed to stay unchanged with the wood frame structure, which is still the standard construction method. Although the industry has witnessed some improvements in methods and materials, the fundamental construction processes remain mostly unchanged with negligible improvements in efficiency.

With the improvement in the US economy, the home building industry is expected to grow in the near future. However, the combination of growing demand for new homes and lack of improvement in the age old construction processes are not helping the industry to be more efficient. A pilot study conducted among several home builders of varied sizes in the Oklahoma City Housing Market Area (HMA) identified delays as one of the major contributors to inefficiencies faced by the home builders in the area. While facing delays is not unusual in the construction processes and can result from a variety of reasons, neglecting to identify the root causes of the delays can be detrimental to the long term success of the businesses. This paper presents the results of an exploratory study to highlight the root causes for delays faced by the home builders. The author borrowed a metric named Percent Plan Complete (PPC) from the framework of the Last Planner System (Ballard 2000) for measuring delays and highlighting the reasons behind them. The key takeaways from this paper are: information about a methodical approach to measure project delays as a function of individual activities, and utilizing PPC metric to systematically identify the root causes of the delays for future planning purpose.

BACKGROUND

Delays are among the most common phenomena in the construction industry across the world – in residential and commercial projects alike. Scholars have investigated the reasons for delays in construction industry in general, but, investigations of delays specifically in the home building industry has not received sufficient attention in the developed nations. Few studies could be found that investigated the construction delays in developing economies such as Thailand (Ogunlana et al. 1996), Hong Kong (Chan and Kumaraswamy 1999), and Nigeria (Aibinu and Jagboro 2002). One commonality among the aforementioned
studies was the use of survey as the research methodology. While survey is recognized as an efficient method of data collection from a sample of respondents from a well-defined population, errors in the sampling technique and respondents' bias can pose questions towards the validity of the findings. To minimize the errors inherent in survey technique, this paper used a metric named PPC to identify the reasons for delays in this study.

**Percent Plan Complete (PPC)**
PPC is used in the Last Planner System® as a metric to measure the variance of activities planned and activities actually completed in the field (Ballard 2000). Thus, in order to calculate PPC it is imperative to quantify the planned activities. To quantify, a detailed scheduling technique is used of listing the activities planned for the following week (Figure 1). Weekly work plan (for week # 2) is prepared at the end of week # 1 based on the look-ahead schedule and actual field conditions. At the end of week # 2, the number of activities that are executed are divided by the number of activities that were listed in the work plan. In addition, the project team identifies and categorizes the major causes of delay. Using PPC to measure delays and identify reasons for delays provides an unbiased method of data collection in comparison to that of survey where the respondents' bias can creep in.

![Figure 1: Process to calculate Percent Plan Complete (PPC)](image)

**RESEARCH METHOD**

The current exploratory study was motivated by the findings of the previously mentioned pilot study conducted among 18 home builders of varied sizes in the Oklahoma City HMA. To explore the reasons for delays, the author adopted a multiple case study method. While convenience sampling was used to include participants, the focus of the study was always kept clear. All the 18 home builders included in the pilot study were contacted to explain the goal and data collection requirement of the current study. Having established initial contact with the participants during the pilot study, the author was fairly familiar with the managements of the companies. The same companies were approached for the current study keeping in mind Mintzberg’s (1979) suggestion of including organizations with well-defined focus to aid in systematic data collection.
Data for the current study was collected using more than one source. The two sources of data collection used for the study was weekly field data in the form of weekly work plan and PPC, and archival data of the participating home building companies. Production control techniques of preparing and maintaining weekly work plan and PPC were new to all the home builders and needed substantial commitment of resources from their part. Due to the increased commitment, only six out of the 18 home builders agreed to participate in the current study. Once the initial buy-in from the six home builders was acquired, the author conducted several workshops on Last Planner System® focusing on ow to develop the weekly work plans and document PPCs. In the initial workshop, the author educated the top management of the organizations about Last Planner System® and the benefits of using different production controls such as weekly work plan and PPC. It was imperative to build confidence among the top management before they enforce their employees and subcontractors to utilize weekly work plan and PPC in their projects. The author conducted subsequent workshops with the project managers and field superintendents of the home builders and the major subcontractors such as concrete, plumbing, masonry, and carpentry. It took almost two months to arrange and offer all the workshops. Once the initial workshops were complete, weekly work plan and PPC were utilized in a total of 18 projects by all the six home builders for a period of one month. No data was used from this period for the study, but was rather used to increase the familiarity of the participants with weekly work plan and PPC and eliminate any misunderstanding.

At the end of one month long dry run, data was collected from 30 different home building projects. Data collection involved measuring the number of activities completed to number of activities planned and identifying the reasons behind the incompletion of all the planned activities. To collect the data, the author required a list of planned activities in the form of weekly work plan and a list of activities completed from the field superintendent. The author kept a control on the quality of data collection by making random visits to the job sites and observing the progress of the projects. A template for data collection was distributed among all the field superintendents as shown below in Figure 2. The observer could select anything from a ‘C’ (to signify complete) to ‘I’ (to signify incomplete). Data using the template was collected from all the 30 projects for a period of 10 weeks. Following collection of data using field observations, archival records of the participating home builders were examined to identify the reasons for delays faced in previous projects. This was done to check the reliability of the field data. The following section will go over the data analysis adopted for the study.

Figure 2: Template used for data collection from project sites

<p>| Project: |<br />
| Location: |<br />
| Observed by: | Start day | End day |</p>
<table>
<thead>
<tr>
<th>Work Days</th>
<th>Activities Planned</th>
<th>Resp. Sub</th>
<th>M</th>
<th>T</th>
<th>W</th>
<th>R</th>
<th>F</th>
<th>Sa</th>
<th>Su</th>
<th>Reasons for incompletion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
With the research goal in mind to explore the reasons behind the delays, the next step was to analyze the reasons for incompletion of the activities. For this purpose, a visual tool was used in the form of Pareto Chart. Pareto chart is a type of bar chart where data is divided into groups and arranged in a descending order as per the frequencies of occurrence. Once the factors were identified from the data collected and arranged in the Pareto chart, the critical factors responsible for the delays could be easily identified.

FINDINGS & ANALYSES

All the six participants can be categorized as spec home builders constructing between 51 to 300 homes per year. Majority of the homes built by these builders are based on speculations. However, they also cater to specific demand by a particular customer or developer. All the participants of the study overall had a similar mode of operation that they followed. Once the plan was finalized and the building permit had been approved, the project manager along with the superintendent prepared a broad level schedule based on experience and intricacies of the particular home. None of them used any sophisticated scheduling software and relied mostly on spreadsheet to prepare and manage the schedule. The subcontractors were allotted time to complete their scope of work based on the schedule. The schedule was very frequently changed based on the subcontractors’ input and resource availability. Once an activity is started, the field superintendent kept track of the trades to inform the succeeding trades about the probable start dates. It appeared that the processes of planning and controls followed by all the participating home builders were very loose and done on ad hoc basis. Data about project updates (completion and non-completion of activities) collected from the superintendents of all the 30 projects.
were recorded followed by calculating the weekly PPC. The graph in Figure 3 shows the combined average weekly PPCs for each of the participating home builders. For each builders, the average PPCs for all their projects were computed and plotted in the graph. The range of the PPC varied from a minimum of 0.46 (realized by Company A) to a maximum of 0.66 (realized by Company E). While no trend was noticed in the graph, the overall low PPC signified low level of planning reliability among the participants. With the loose method of planning and scheduling followed by these builders, the low values of PPC were anticipated. In general, the incompletion of the activities to a large extent were due to unrealistic production planning and lack of communication among the subcontractors.

As the focus of this study is to explore the causes for incompletion of activities and hence the reasons for delays, the author modified the PPC metric to Percent Plan Incomplete (PPIC) where PPIC is the ratio of incomplete activities to activities planned or calculated as equal to 1-PPC. The purpose for this modified metric was to focus on the incomplete activities. The PPIC data was next plotted on a Control Chart to identify the variations in the process. Among the different Control Charts, the p-chart was found to be most suitable for the current study due to the variable sample size. Typically, in a p-chart a statistical range is set while plotting the data. The range can be set by defining an upper control limit (UCL) and a lower control limit (LCL). The control limits can be set by the company based on the customers’ needs or mathematically set as shown below.

\[
UCL = PPIC_{avg} + STD \, DEV. \\
LCL = PPIC_{avg} - STD \, DEV.
\]

Where,

\[
PPIC_{avg} = \frac{\sum \text{Incomplete Act}}{\sum \text{Act Planned}}
\]

\[
STD \, DEV. = \sqrt{PPIC_{avg}(1 - PPIC_{avg})} / \sqrt{ActPlanned}
\]

The daily incomplete activities for the individual projects were plotted in separate p-charts to identify the variations in the processes (Figure 4). Using the LCL as equal to zero, the process observation data was only plotted against the UCL. The varying UCL values of each day is due to the varying number of activities planned for each day (Appendix – I). The PPICavg for any given day should not be more than the UCL of that day. However, in Figure 4 it is clearly evident that for few days (days # 36 and 40) the incomplete activities were more than the UCL values. These are instances of variations caused due to external factors that can be eliminated without changing the overall process. Days when these variations occurred were identified from the p-chart and the reasons for incompletion of activities were identified as shown in Table 1.

![Figure 4: A typical p-chart plotted for one of the study projects](image-url)
This process of plotting p-charts of daily incomplete activities and identifying the external causes of variations were repeated for all the 30 projects. P-charts for all the 30 projects are not included due to space limitations. The reasons for incomplete of activities from all the 30 projects were coded and stratified into six groups using a Pareto Chart (Figure 5). The chart shows that ‘supplier’ caused majority of the incomplete activities in the observed data. The code ‘supplier’ was applied to all the reasons related to deliveries arriving late, deliveries of wrong materials, as well as inappropriate quantities of materials delivered. ‘Over-assignment’ appeared as the second most frequent reason causing delays to the projects. The code ‘over-assignment’ was used when the crew could not complete the assignment in the given duration. This was mainly due to over planning by the site superintendents without consultation with the workers. The delays caused due to over-assignments had a profound effect than those caused due to delivery issues. If a particular activity could not be completed on the scheduled day due to over-assignment, it has to be completed in the next day thus affecting the output of the next day as well. If this scenario is considered over a week’s time, every day a few of the scheduled activities could not be completed as the incomplete activities of the previous day had to be completed first. The third most frequently occurring reason that caused delays was due to ‘no show’. This code was used whenever the crew did not show up for work and thus caused the delay. ‘Work not ready’ code was applied when pre-requisite works were not completed before the particular activities could be undertaken. This way delays were transmitted from one activity to another. Reasons within this code signifies a lack of reliability in the planning process. ‘Quality issues’ was used as the reason code in instances when the work was not conforming to the construction drawings and specifications. The ‘other’ code was used when the planned activities could not be completed due to weather conditions, owner driven changes, and unavailability of inspectors.
The Pareto analysis was also used to stratify the observed data based on trade type. The chart in Figure 6 shows proportion of incomplete activities associated with the different trades. The chart shows that the ‘masonry’ trade had the most number of incomplete activities associated with them followed by ‘rough carpentry’. The other trades that accounted for at least 10% of the incomplete activities in the observed data were ‘plumbing’, ‘trim carpentry’, and ‘drywall’. The following stratification by trade provided an insight into the reasons for such performance and an opportunity for further examination.
CONCLUSIONS

With the demand for new homes expected to increase steadily in the future, it is necessary to scrutinize the current processes of home building and make a concerted effort towards improving it. The current study is a step towards exploring a methodical approach to identify and categorize the root causes for delays to learn for future planning purpose in the home building industry. The study employed a multiple case study approach to collect data from 30 different projects for a period of ten consecutive weeks though observation and input from the site superintendents. The author adopted the PPC metric used in the Last Planner System® for data collection. The format used for data collection was simple and easy to use. Some of the site superintendents involved in the study adopted the metric for future use with minor modifications tailored to meet their specific needs. It was easily realized that the practice of collecting daily and weekly PPC is only possible if the format for data collection is simple and not time consuming. PPCs of the individual projects as well as combined PPCs for each companies were calculated. The PPCs plotted for the ten weeks’ time showed a range of 0.46 to 0.66. That means anywhere from 54% to 34% of the scheduled activities were not completed on a weekly basis in the projects included for the study and end up being delayed. While delays occurring due to incompletion of activities are the symptoms, it is critical to identify the root causes of the problem. To examine the root causes, the author prepared p-charts for all the individual projects to focus on the incomplete activities and the causal reasons behind them. Based on the p-charts, the days when the incomplete activities were more than the UCL values were selected and the reasons causing the incompletion were identified. From an operational perspective, an external cause of variation can be easily removed without any modification necessary to the existing process.

Stratification of the observed data using Pareto charts showed that issues related to deliveries arriving late or deliveries of wrong materials, which were categorized as ‘supplier’ caused the majority of the incomplete activities in the observed data. This was followed by reasons related to category ‘over-assignment’. Delays due to over-assignment could be due to multiple reasons such as wrong assignment of tasks, the workers not performing at the expected level, or communication gap between the superintendents and the workers. Interestingly, examination of the archival data of the participating builders also indicated issues with deliveries that supported the findings of this study. No archival data on the actual performance of the workers could be found. However, the superintendents mentioned low productivity of the workers as one of the major reasons for delays. The superintendents were also not confident of the production plan to an extent where they could track the expected and actual productivity of the workers. Having identified the root causes of the delays directly linked to the loose and short term planning approaches, the builders could look into investing in preparing comprehensive schedule for the entire projects. This would lead to better communication between the builder and the trades and probably less occurrences of over-assignment and no shows. Using the approach described in the paper to identify the trades who are more prone to delays can assist the builders to secure firm commitments regarding their crew availability and production rates. A step further can be focusing more on the activities involving the ‘high risk’ trades in the comprehensive schedule and scrutinize their performance against base schedule.

The impact of the incomplete activities on the overall project such as cost, quality, safety, or client satisfaction was not captured for this study. It is obvious that the impact of delay will
vary from case to case; it is not possible to identify any trend at this point. Nevertheless, the outcome of this study illustrates a methodical approach to measure project delays as a function of individual activities, and how identifying root causes responsible for delays can be used by the builders for future planning purpose.

REFERENCES


### APPENDIX – I

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Using Percent Complete Metric to Highlight the Root Causes of Delays in Home Building Industry

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