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Scope: The Journal of Management and Engineering Integration (JMEI) is a double-blind refereed journal dedicated to exploring the nexus of management and engineering issues of the day. JMEI publishes two issues per year, one in the Summer and another in Winter. The Journal's scope is to provide a forum where engineering and management professionals can share and exchange their ideas for the collaboration and integration of Management and Engineering research and publications. The journal will aim on targeting publications and research that emphasizes the integrative nature of business, management, computers, and engineering within a global context.

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The Journal Editorial Team would like to thank the reviewers for their time and effort. The comments that we received were very constructive and detailed. They have been very helpful in our effort to continue to produce a top-quality journal. Your participation and timely response are very important for the success in providing a distinguished outlet for original articles. In this issue we continue to include Keywords, and the dates the publication was submitted and revised in an effort to achieve a higher standard for publication and increase the impact of the journal.

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A Framework to Define and Quantify Leadership Styles within Navy Engineering Units

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Abstract

The purpose of this study was to develop a framework for the U.S. Navy's leadership styles by assessing self-perceived leadership styles in a sample of reserve Engineering Duty Officers (EDOs) and the Senior Enlisted Leaders (SELs) in these technical units. Transformational and transactional leadership styles were examined using the Multifactor Leadership Questionnaire (MLQ) Form (Avolio & Bass, 2004), while the servant leadership style was examined using the Servant Leadership Self-Assessment Questionnaire (SLSQ) (Sandling, 2021). The effect of rank and the triad leadership position had on leadership style was explored in this study. The survey was made available to all EDOs and SELs (n = 525). A total of 84 surveys were completed (a 16% return rate). Results showed that there was a statistically significant difference in servant leadership between SELs and junior officers. When broken down into the factors of servant leadership this difference was seen in the conceptual skills and putting followers first factors. No statistical differences were seen across leadership triad positions, or between any other ranks for any other leadership style. The findings are discussed for their implications for leadership development in the U.S. Navy.

Keywords: Leadership Styles, Multifactor and Self-Assessment Questionnaires.

1. Introduction

Transformational leadership studies that have been completed focus on transformational versus transactional leadership exclusive of servant leadership. Unfortunately (perhaps due to societal values or perhaps due to the chosen names), transformational leadership has been touted as good or desirable, while transactional leadership has been denigrated as bad, basic, or detrimental. This dichotomy does not exist in actuality as there are numerous successful transformational as well as transactional leaders. This study sought to develop a framework of the leadership styles that exist within a successful naval reserve unit by surveying its leaders.

The traditional leadership continuum used in the MLQ survey involves transformational, transactional, and laissez-faire leadership (Bass, 1985, 1998). Laissez-faire leadership, as defined by Bass (1998), consists of not making necessary decisions and ignoring the responsibilities of leadership. In the military's chain of command structure, laissez-faire leadership is not a valid option that would allow a sailor to retain a billet.

Transformational leadership is a leadership style where leaders strive to motivate employees to do more than they originally thought they were capable of achieving. This leadership style would seem to

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fit senior officers or commanding officers who are trying to get their sailors to perform extraordinary tasks. Transactional leadership is a leadership style where leaders identify the needs of their subordinates and motivate them to accomplish goals with appropriate rewards for their performance. This leadership style would seem to fit a junior officer or even an executive officer as they focus on accomplishing the day-to-day activities of a unit. Servant leadership differs from these leadership styles as leaders put the needs of others before their needs. This seems indicative of an SEL as they focus on bringing their sailors up through the ranks. An initial framework was developed to depict the theorized interactions expected to be discovered in this study, Figure 1.

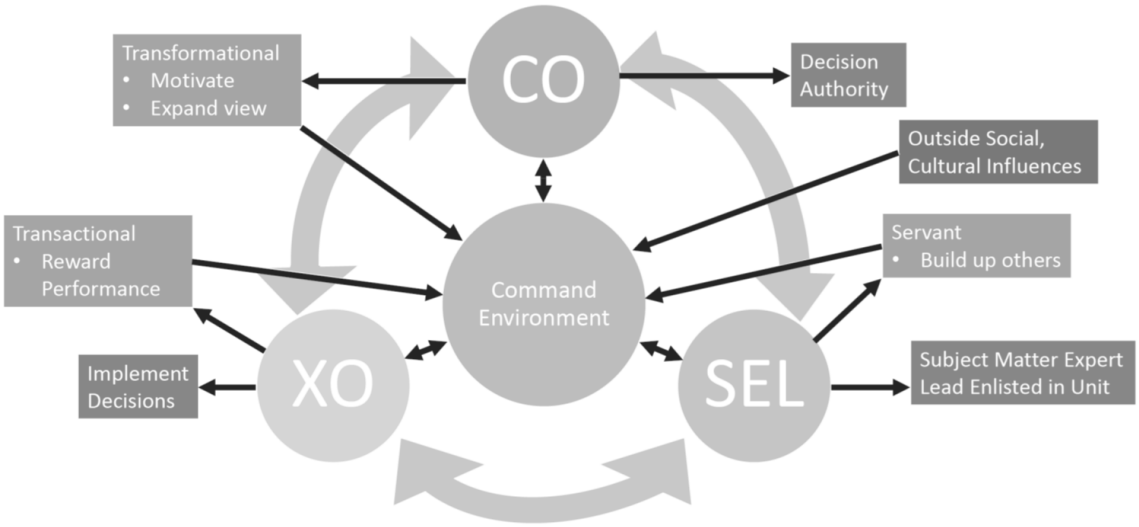

Figure 1. Initial framework

The research questions to be addressed by this study are as follows:

Research Question 1: Is there a relationship between military rank and transactional leadership?

Research Question 2: Is there a relationship between military rank and transformational leadership?

Research Question 3: Is there a relationship between military rank and servant leadership?

Research Question 4: Is there a relationship between a triad leadership position and transactional leadership?

Research Question 5: Is there a relationship between a triad leadership position and transformational leadership?

Research Question 6: Is there a relationship between a triad leadership position and servant leadership?

2. Method

This non-experimental correlational study was designed as a quantitative research study employing a survey to collect data to determine to what extent transformational, transactional, and servant leadership styles exist at the various ranks within the EDO community and the units they lead. This section reports on the sample, research instrument, and data analysis.

2.1. Sample

The target population sample includes approximately 525 participants with 448 EDOs and 77 SEL service members. EDOs are highly educated, with a minimum of a technical master's degree required to become a member. SELs are subject matter experts in their rates. The entire population was invited to participate in the study through announcements, e-mails, and text. A total of 84 surveys were completed (16% response rate) and represented 10% of the SELs and 17% of the officers.

2.2. Instrument

This study used three data collection instruments, the MLQ Self Form, the SLSQ, and a demographic survey. The MLQ Self Form is an approved adaptation of Bass and Avolio's MLQ survey. The SLSQ is a version of the 2008 SLQ survey developed by Liden, Wayne, Zhao, and Henderson that was adapted for an individual leader by Sandling (2021). The demographic survey collected the participant's rank (SEL, junior officer, or senior officer), age (from a range), civilian career level, if the participant held a triad leadership position (commanding officer, executive officer, or SEL), prior-enlisted experience, and highest degree level. The survey did not ask for gender or ethnicity as these distinguishers could make some participants identifiable when combined with other demographic data.

2.3. Data analysis

The MLQ scored leadership with nine factors: five for transformational leadership, two for transactional leadership, two for passive avoidant, and three for additional characteristics. A participant's score was determined by averaging the factors that pertain to each leadership style. The results for passive avoidant and the characteristics were not used in the data analysis of this study. The SLSQ scores were determined over seven factors. These factors were averaged and subsequently converted to a five-point scale result so they could be compared with the results of the MLQ. To examine the significant differences in leadership style by rank and leadership triad position an ANOVA was performed with Tukey post hoc analysis of Welch's ANOVA with Games-Howell post hoc analysis when homogeneity was violated.

3. Results

This study found the mean for servant leadership in SELs (4.21) was statistically significant from junior officers (3.93), $F(2, 81) = 3.408$, $p = .038$. When servant leadership was broken back down into its factors, a statistically significant result was seen across conceptual skills and putting followers first. The conceptual skills factor was significant between SELs and junior officers ($p = .029$) while putting followers first was significant between SELs and junior officers ($p = .004$) as well as SELs and senior officers ($p = .007$).

There was no statistical significance found for servant leadership and leadership triad position, but since it was close to being significant it was broken down into its factors to determine any significance. In this case, a statistically significant result was again seen across conceptual skills and putting followers first. The conceptual skills factor was significant between SELs and executive officers ($p = .023$) while putting followers first was significant between SELs and commanding officers ($p = .022$).

No other combination of leadership, rank, leadership triad position, or factor of any of the leadership

styles resulted in any statistically significant result. To ensure no other measurable data played a role in the leadership style, the means were compared across all of the demographic data available. Nothing else was found to yield a statistically significant result.

Table 1. Summary of MLQ and SLSQ Scores

	Transactional	Transformational	Servant
SEL	3.52	4.13	4.21
Junior Officer	3.30	3.93	3.93
Senior Officer	3.35	4.04	4.03
SEL	3.40	4.03	4.18
Executive Officer	3.31	3.88	3.92
Commanding Officer	3.43	4.05	3.97

4. Conclusions

Leadership has always been an important subject for the military, and it will continue to be the subject of many future studies as the military seeks to retain its edge over any threats or potential aggressors. The findings of this study suggest that leaders in this study use a toolbox that contains all of the leadership styles approximately equally. The statistically significant difference observed in servant leadership for junior officers could be attributed to the few or lacking subordinates for some junior officers. Junior officers may not rely as heavily on servant leadership because they feel like they have no one below them to mentor. When soliciting responses for this survey, comments from junior officers indicated they did not view themselves as leaders, did not want to skew the survey with their responses, or did not see their importance as they hadn't done anything in the military yet, despite some of the participants having held command positions previously.

By breaking the leadership means into their component factors, additional insight into the servant leadership significant was discovered. When grouped by rank, the SELs and junior officers' mean had significant differences over the conceptual skills factor. The conceptual skills factor is defined by Liden et al. (2008), as "possessing the knowledge of the organization and tasks at hand so as to be in a position to effectively support and assist others, especially immediate followers" (p 162). In the Navy there is a saying, ask the Chief, the saying isn't, ask the junior officer. SELs have the reputation for knowing everything, where to get it, or whom to get it from.

Putting followers first was the other component factor SELs had statistical significance from both junior and senior officers. This factor is defined by Liden et al. (2008), as "using actions and words to make it clear to others (especially immediate followers) that satisfying their work needs is a priority" (p 162). This falls in line with the original hypothesis of the study. SELs look to build the community of their fellow sailors. They participate in mentoring, career counseling, and study sessions for their rate exams for promotion.

These two factors also had statistical significance when the triad leadership position servant leadership mean was broken back into its factors. The conceptual leadership factor had statistical significance between SELs and executive officers. Executive officers are often more junior than the SELs, so it is not surprising that the executive officer may feel like they don't yet have the capability to

effectively support others initially. SELs with their years of experience would likely have less uncertainty in their organizational knowledge and their ability to help their fellow sailor.

4.1. Implications of the study

This study examined a group of successful leaders to determine the leadership styles they use. The results indicate that across all ranks and triad leadership positions a mix of all leadership styles are used. Even the exception of the one significant result did not negate the use of servant leadership by junior officers, but just that they did not identify as using it as much as the SELs. This suggests that to be a good leader, a leader has to pull from all of these leadership styles to be able to lead effectively. Different leadership challenges may be better solved with different approaches rather than applying a particular leadership style to every situation.

Previous studies have analyzed different types of leadership styles, but no study could be found that combined these three leadership styles. The MLQ tests transformational, transactional, and laissez-faire; the latter being a lack of leadership. Servant leadership studies generally study servant leadership by itself against a variable like job satisfaction. This study instead addressed servant leadership at the same level as transformational and transactional leadership.

The lower junior officer mean for servant leadership shows an area with room for improvement. SELs had a significantly larger servant leadership mean, but senior officers also had a larger servant leadership mean. Both SELs and senior officers were selected for promotion from a competitive group of leaders all looking to advance. If the boards selecting these senior leaders are selecting sailors with the traits of servant leadership, then it is worth emphasizing in leadership courses to junior officers to grow an increasingly effective and competitive group of officers.

This study could be applied to other military communities outside of engineering to determine if a leadership style is missing from the mix of styles that that community is employing. The successful application of all of these leadership styles has ensured success for the EDO community and could serve other communities in the future.

5. References

Avolio, B. J., & Bass, B. M. (2004). Multifactor leadership questionnaire, Manual and Sample Set (3rd ed.). *Mind Garden, Inc. Menlo Park, CA.*

Bass, B. M., & Bass Bernard, M. (1985). Leadership and performance beyond expectations.

Bass, B. M. (1998). Transformational leadership: Industrial, Military, and Educational (Lawrence Elbaum Associates Publishers, Mahwah).

Liden, R. C., Wayne, S. J., Zhao, H., & Henderson, D. (2008). Servant leadership: Development of a multidimensional measure and multi-level assessment. The Leadership Quarterly, 19(2), 161–177. Elsevier BV. https://doi.org/10.1016/j.leaqua.2008.01.006

Sandling, J. (2021). Servant Leadership Questionnaire Self-Assessment. https://jonathansandling.com/free-servant-leadership-questionnaire-self-assessment/.

Evaluation of a Hybrid Cold Spray and Machining Method for Fabrication of Parts with High Surface Integrity

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Abstract

Cold spray technology has been proven to have various engineering and manufacturing applications, including the capability to restore previously unrepairable parts. However, like most additively manufactured parts, it will likely require post-processing, such as machining, to improve surface finish and dimensional accuracy. In addition, cold spray deposits are typically porous. The porosity may be detrimental to the mechanical performance of the component. This paper presents a systematic evaluation of cold spray using readily available nitrogen as carrier gas, subsequent machining utilizing negative rake angle tools, and the effect of this novel hybrid fabrication method on subsurface porosity. The machining is optimized via finite element analysis (FEA) and the optimum is verified by experiments. The analysis informs the engineering of the proposed hybrid cold spray/machining method.

Keywords: cold spray, machining, negative rake angles, finite element analysis (FEA), aluminium, porosity

1. Introduction

The cost of corrosion-related maintenance and failures within the US defense in 2002 was estimated to be $20 billion (Koch, Brongers, Thompson, Virmani, & Payer, 2002). Localized corrosion damage increases safety risks. The cost of repair by component replacement is usually too high. One alternative to replacement is repair. For repair to be successful, the applied technique should preserve the substrate, and avoid inducing detrimental residual stresses or microstructural changes. Cold spray technology has been investigated for its ability to restore damaged, corroded surfaces (Yin, et al., 2017). The technology has also been adopted as an efficient, direct fabrication route for entire parts of an assembly (Kilchenstein, 2020). Therefore, cold spray also offers a route for direct production of replacement parts, potentially in a cost-effective manner. When compared to other, fusion-based additive manufacturing processes, cold spray presents several advantages. It preserves or improves the mechanical properties of the feedstock, produces oxide-free deposition and produces minimal heat affected zones (Yin, et al., 2017). Therefore, it has a negligible effect on the substrate's mechanical and microstructural integrity. Compared to powder bed fusion (PBF) and directed energy deposition (DED), cold spray offers high production rates (Champagne and Helfritch 2014). Furthermore, cold spray is

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particularly attractive for high-reflectivity metals such as aluminum and copper, which are extremely challenging to manufacture using laser based processing (Yin, et al. 2017). However, cold spray deposition is limited by poor surface quality, poor dimensional accuracy, and high porosity (Yin, et al. 2017). The carrier gas required to accelerate the particles for adequate particle bonding, traditionally helium, is also in short supply and is costly. An alternative that has been investigated is the use of readily available nitrogen, but use of this carrier gas results in even higher porosity (Zahiri, et al. 2006). Processing after cold spray deposition by machining and heat treatments is generally needed to improve the properties of the deposition (Yin, et al. 2017).

The work presented herein introduces a systematic study of cold spray deposition of an aluminum alloy using nitrogen as the carrier gas, and special cutting tool geometric parameters that may enable porosity closure on the subsurface of the tool. Machining conditions leading to acceptable levels of porosity in the subsurface of this cold sprayed deposition are recommended. It is expected that the machined subsurface with reduced porosity will have improved fatigue performance, as it is generally the case (Sample, Champagne, Nardi, & Lados, 2020).

2. Background

Typical fundamental research and commercial application of cold spray processing indicate that it is required to apply post cold spray processes such as machining, to correct the irregular and dimensionally inaccurate deposition. Cold spray nozzle and powder feedstock design, and optimization of cold spray performance measures based on scanning speed/number of passes, nozzle-deposit standoff distance and other inherent process parameters may yield predictable deposits with increased shape and dimensional accuracy, but these optimization efforts still lag shape and dimensional accuracy that may be obtained by advanced machining (Champagne & Helfritch, 2014). Therefore, systematic studies of the machinability of cold spray deposition such as the one presented in this work are technologically relevant. It has been suggested that the machining characteristics of cold spray deposits are like those of traditional powder metallurgy components. These porous materials typically induce variations in mechanical and thermal loads on the cutting tools, potentially due to the segmented chips formed after cutting porous materials (Yin, et al., 2017). Just as demonstrated for other additive processes (Kumar Ananda, 2017), finishing cold spray deposits by machining would require unique sets of process parameters, to accommodate the unique microstructure resulting from the deposition.

Most of the research about the characteristics of the surfaces produced by machining focuses on surface topography and surface mechanical properties including wear and fatigue characteristics (e.g., (Pandey, Reddy, & Dhande, 2003) and (Gunay, 2008)). However, the work of (Kaynak & Kitay, 2018) pointed to noticeably reduced porosity density on the subsurface of machined stainless steel fabricated by selective laser melting. Furthermore, studies by (Heidari & Yan, 2017) and (Panzera & Campos Rubio, 2005), indicated that diamond turning of carbon and machining of ceramic composites showed porosity reduction sufficient for air bearing applications.

Tool rake angle is one of the most important geometrical parameters affecting machining force and workpiece subsurface (Rios, Hernandez, Llave, & Koubaa, 2013). Changing the tool from just plus 5° to minus 5° resulted in significant increase of machining force (Ipilakyaa & Gundu, 2017). The work of (Zuo, Meng, Zhou, & Liu, 2022) and (Bao, et al., 2023) indicated that making the tool rake angle more negative

increased the compressive stress applied on the workpiece by the tool. Cutting with some level of negative rake angle has even been reported to decrease surface roughness (Nagakalyan & Ramalinga Reddy, 2023). When working with rake angles as negative as -30°, the subsurface deformation has been reported to be more than 100% at subsurface depths of about ¼ to ⅓ of the depth of cut (or feed) (Guo, M'Saoubi, & Chandrasekar, 2011).

3. Preliminary finite element modeling of machining

The geometric configuration of the machining process being modeled is illustrated in Figure 1. From this figure, it appears that the severity of the constraint imposed by the tool on chip flow increases as the rake angle decreases (compare label "1" – with positive rake angle and label "3" – with negative rake angle). The rake angle is typically about zero (neutral, as in label "2" in the figure), and the deformed layer under the surface created by the cutting is typically a small fraction of the tool feed (or depth of cut) (Guo, M'Saoubi, & Chandrasekar, 2011). However, it was hypothesized that very negative rake angle tools may induce a much larger deformed layer, and that the strain over much of this deformed layer would be sufficiently severe to close pores in cold spray deposited materials.

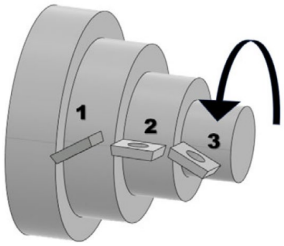

Figure 1. Schematic of turning.
Negative rake angle (label 1), neutral rake angle (label 2), and positive rake angle (label 3).
The arrow indicates workpiece direction of rotation.

A mechanical scenario (i.e., and FEA model) was created using the CATIA Part Design, SIMULIA and Mechanical Scenario Creation applications of the commercial software 3D Experience® to model the plastic deformation caused by cutting tools of very negative rake angles on the subsurface of the workpiece. This model was setup to verify the first part of the hypothesis mentioned above. The FEA included an explicit dynamic solver with quadratic meshing. The tools received a tetrahedral mesh of overall size = 1.75 mm, but the elements near the tool cutting edge were of size = 250 μm. The workpiece had a fine square mesh of size 1.25 mm. Temperature rise was neglected since the effect of rake angle on subsurface deformation strain was the subject of interest. The rake angles were -55°, -65° and -75°. The cutting edge radius was about 500 μm. This is much larger than the edge radius of the tool used for the experiments, which was 24 μm. However, the simulated edge radius was as small as the level of computational power allowed. The depth of cut (or, as usually known in turning, the feed) was also varied between 0.8 mm and 1.8 mm. The results are shown in Figures 2A and 2B. Figure 2A shows the effective strain induced under the machined surface as functions of the rake angle and the depth of cut. The view is the plane formed by the cutting direction and the direction of tool penetration (depth of cut, or feed). According to FEA, the strain in the subsurface at any given depth is maximum for the negative rake angle of -55°. Therefore, the finding from the FEA implies that this strain increases with decrease in rake angle up to some rake angle beyond which the strain decreases with decrease in rake angle. This

strain also increases monotonically with increases in depth of cut. For tool rake angle of -55° and depth of cut of 1.3 mm, the subsurface strain reaches about 1.7 at subsurface depths of 50% of the depth of cut. Figure 2B shows a cross section of the strain field under the cutting edge. From this figure, it is apparent that the strain field is severe and uniform along the cutting edge, but it reduces significantly near the lateral free faces of the workpiece. However, the fraction of the width of cut over which the subsurface strain is uniform and severe is over 85%.

The FEA results indicate that it is possible to induce severe strains under the machined surface with a sufficiently negative rake angle. There appears to be, however, an optical rake angle that induces the most severe subsurface deformation. With this optimal rake angle, the subsurface deformation layer is a significant fraction of the machining feed. The experiments described next explore the effects of machining with very negative rake angles on the porosity of cold spray deposition.

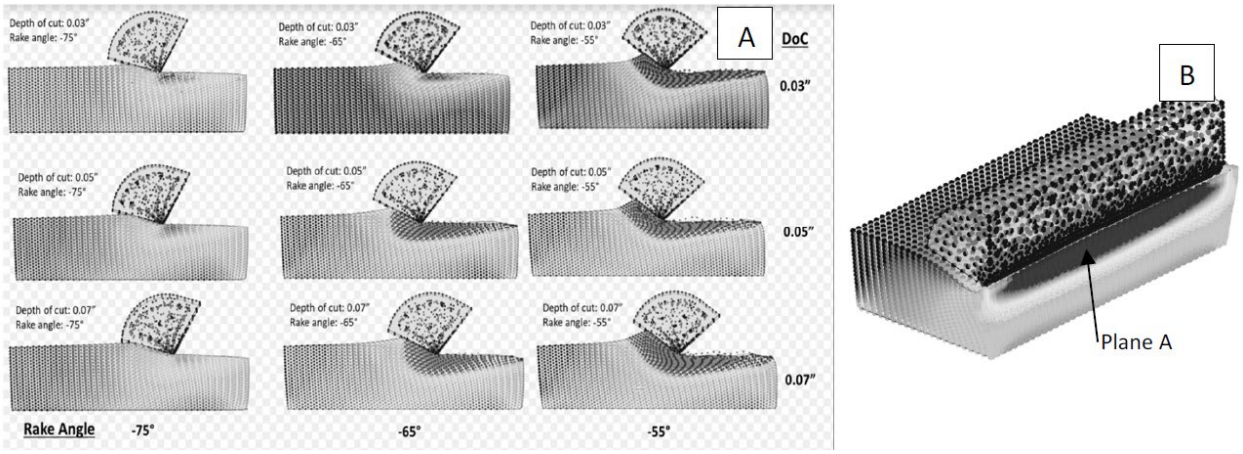

Figure 2. A) Finite element modelling of negative rake angle to observe plastic deformation on the machined subsurface. Relative gray scales. All images on the same scale. All images from the same time through the cutting. B) Cross section parallel to the cutting edge showing plastic deformation under the machined subsurface, and the uniformity of this deformation along the width of the cut (along the cutting edge). Relative gray scale. Dark = high plastic strain, light = low plastic strain.

4. Experimental configuration

A free-form cold spray deposition method shown schematically in Figure 4A was used to deposit aluminum 6061 on a substrate (a piece of aluminum 7075). The deposition followed proprietary conditions of gas pressure and temperature, feedstock sphericity, nozzle geometry and standoff distance, deposition kinetics (scan velocity and number of passes). The feedstock was in the form of powder of size (diameter) 1 to 50 μm. It received heat treatment to remove moisture just prior to deposition. The carrier gas was nitrogen. While the specifics of the deposition cannot be made public, the resulting material had an average porosity concentration, by area fraction, of 2.7%, with standard deviation of 0.8%. The porosity concentration was obtained following microstructural analysis as will be explained in the forthcoming. Although recently applied cold spray conditions have resulted in lower porosity concentration, so far, using nitrogen gas as carrier, the porosity concentration remains higher than that obtained when using helium as carrier.

A controlled machining process was performed to close pores on the subsurface of the cold sprayed

material. For this purpose, disks having a diameter of 25 mm were prepared by milling from the sprayed cuboids. The disks were mounted on the end of a round bar and turned to make concentric with the bar. A positive rake angle tool and small feed was used to ensure that the subsurface of the disk was not altered by this disk preparation process.

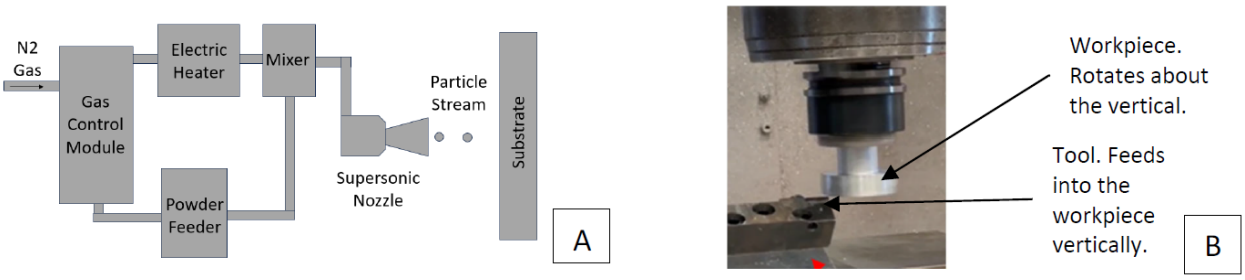

Figure 4. A) Schematic of the cold spray deposition process. B) The apparatus used for the controlled machining experiments.

The controlled machining was in the form of single-point turning of the disk held on one end of the round bar, which was mounted on the spindle of a machine tool, as shown in Figure 5. Feed of 300 μm/rev, width of cut of 1.3 mm and cutting speeds of 0.5 m/s or 1 m/s were applied. The tool rake angle was varied intentionally. It was set to -10°, -25° and -50°. The controlled machining was stopped after a cutting length (measured parallel to workpiece axis) of 1 or 2 mm. It is well known that the cutting speed has a second order effect on the strain produced by machining on the deformation zone ahead of the tool (Boothroyd & Knight, 2006). Therefore, the effect of the cutting speed variability during the controlled machining experiments on subsurface deformation may be neglected. Moreover, as can be seen in the results section, the applied feed was larger than the extent of the induced subsurface deformation. Hence, the deformed subsurface layer should have been produced by the last workpiece rotation, and stopping the cutting after different cutting lengths should not result in altered subsurface deformation. The reduced cutting speed (0.5 m/s) and cutting length (1 mm) was necessary for the cuts with the -50° rake angle tool due to excessive tool vibrations. The cuts with the -10° and -25° rake angles were performed at the higher cutting speed (1 m/s) and longer cutting length (2 mm).

Cross sections of the specimen were prepared for metallography by standard sample preparation methods that involved first grinding with abrasive paper and then polishing with a diamond slurry. The porosity concentration was measured using the open source application “ImageJ” from the National Institute of Health (NIH) (Image Processing and Analysis in Java – ImageJ, 2018). The measured porosity represents area fraction. The porosity of the material prior to controlled machining was obtained by polishing away from surfaces that may have been modified by post spray processing.

5. Experimental results

Figure 5 shows micrographs characterizing the porosity under the machined surface for the three negative rake angles that were deployed. The viewing direction is that of the plane parallel to the cutting edge and the feed direction. This is also plane A shown in Figure 2B. Note, in Figure 5, the grid used to partition the subsurface into mosaics, for statistical analysis. This figure represents the typical distribution of porosity obtained after polishing one cross section under the machined surface. The pores are the black dots evident in the figure. For statistical confidence, at least two cross sections for

each rake angle were prepared, segmented, and analyzed for porosity. Figure 7 shows the distribution of porosity, expressed as pore area fraction. Each data point in Figure 7 represents the mean porosity concentration obtained for a given mosaic in the subsurface. The error bars represent the range of porosity concentration measured for each mosaic. The "plus" and "minus" error bars are each one half the range of porosity concentration. Note that the mosaics shown in columns 1 to 6 of the analyzed region are the ones directly under the cutting edge. Mosaics shown in columns 7 to 14 are in the far region where, from the FEA presented above, the tool imposes no strain, and the porosity should be unaltered.

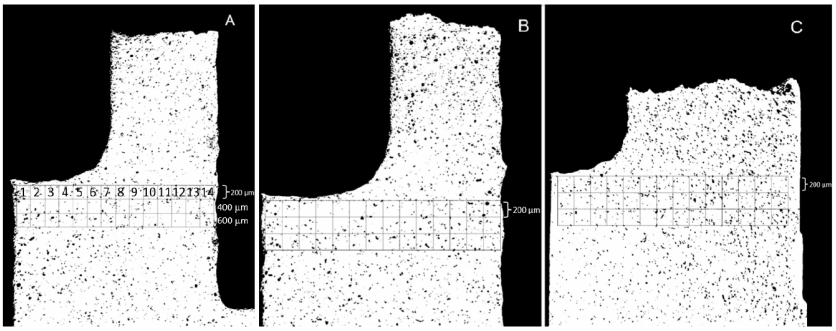

Figure 6. Porosity distribution after machining with negative rake angles. A) Rake angle = -10°, B) rake angle = -25°, C) rake angle = -50°.

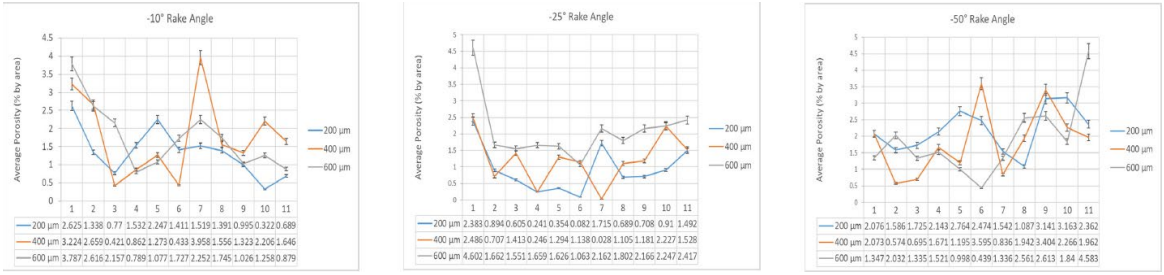

Figure 7. Porosity distribution after machining with negative rake angles as shown.

From Figure 7, it is apparent that tool rake angles of -10° and -25° induce a significant reduction in porosity up to subsurface depth of 200 µm (or about ⅔ of the feed). The porosity reduction is most significant for the -25° rake angle. At depth about ⅔ the feed, the porosity reduces from 2.7% ± 0.8% in the base material to 1.5% ± 1.5% at -25° rake angle. However, at larger subsurface depths, or at any depth under the -50° rake angle, there is no significant reduction in porosity. There is also a tendency to relatively high porosity near the free lateral side of the workpiece (see mosaics 1 or 2 in Figure 7).

6. Discussion

Cold spray deposition using nitrogen gas as carrier is attractive due to the wide availability and low cost of nitrogen, compared to the typically used helium gas carrier. However, deposition with nitrogen leads to increased porosity that may compromise the mechanical integrity of parts repaired or produced by cold spray deposition. The results shown herein indicate that it is possible to "engineer" the machining process to reduce porosity in the subsurface of cold sprayed materials. A path to optimization of the hybrid cold spray and machining process leading to minimal porosity near the material/part surface is laid out in Figure 8. This path involves optimization of cold spray conditions mainly by

experimental means, and optimization of machining by combined FEA and experimental techniques as described in detail in the above sections.

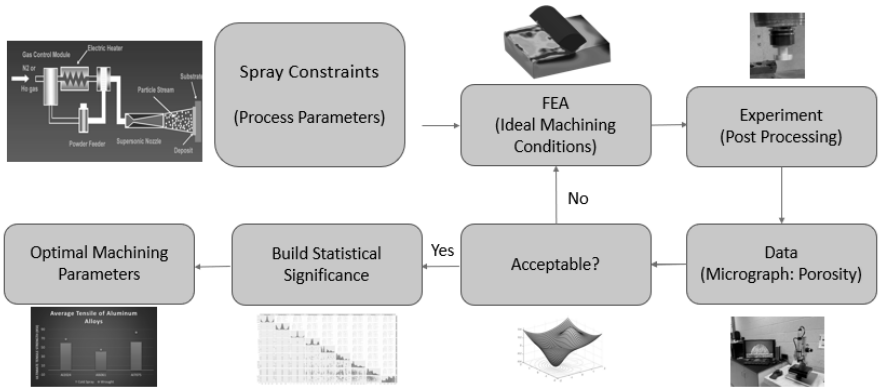

Figure 8. Process map, from cold spray to minimal porosity after optimal machining parameters.

The machining process engineering will likely require cutting with a very negative, but definite rake angle tool. The optimal rake angle may be identified after a compromise between induced subsurface deformation and other performance measures such as surface roughness and machining force (or energy consumed during cutting). The data presented in the preceding sections indicate that a negative rake angle of about -25° would likely reduce porosity by about a factor of2 at subsurface depth of about ⅔ the feed that is selected. The porosity concentration that is achievable is under 1.5%, which is close to that obtained from cold spray using helium gas as carrier, and to that obtained from other standard pore closing processes such as hot isostatic pressing (Yin, et al. 2017). The FEA also indicates another possible route. Extreme negative rake angle tools may suppress chip formation. Although with these extreme negative rake angle tools the strain induced in the subsurface may not be the maximum, making such a tool pass multiple times over the same area of a workpiece would result in strain accumulation, since material would not be removed from the workpiece. The degree of strain accumulation shall be characterized by FEA and experimental work. It was noted during the experiments that these very negative rake angles lead to pronounced machine tool vibrations and poor surface finish. Therefore, this proposed alternative needs to be considered from the point of view of machine dynamics. This alternative will be considered as part of future work.

7. Conclusion

Cold-sprayed Al6061 using nitrogen gas as alternative carrier following a partially optimized process, described in detail in body of this report, was evaluated for porosity concentration. The porosity concentration, defined as pore area fraction, was obtained as 2.7%±0.8%. This is a higher porosity concentration than typically obtained by more conventional cold spray deposition using helium gas as carrier. However, the porosity near the surface of the deposited material may be significantly reduced by a hybrid clod-spray/machining method. The machining shall be performed with a very negative rake angle tool (e.g., -25°) at conventional machining feeds of about 300 μm. With this choice, the porosity at subsurface depths of about ⅔ the feed may reduce from 2.7%±0.8% to 1.5±1.5%. An alternative involving chip suppression by cutting with extremely negative rake angle tools was also identified as a potential route to produce subsurface strain accumulation by multi-pass machining. This alternative will be explored in more detail as part of future work.

8. Acknowledgements

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9. References

Bao, X., Yao, P., Xu, J., Mei, Z., Yueming, L., Yang, J., . . . Huang, C. (2023). Effect of Tool Geometry and Cutting Parameters on Surface Quality and Chip Morphology of Amorphous Electroless Nickel-Phosphorus Alloy in Ultra-Precision Turning. *The International Journal of Advanced Manufacturing Technology*, 2461-2478.

Boothroyd, G., & Knight, W. A. (2006). *Fundamentals of Metal Machining and Machine Tools*. CRC Press.

Champagne, V., & Helfritch, D. (2014). Critical Assessment 11: Structural Repairs by Cold Spray. *Materials Science and Technology*, *31*(6), 627-634.

Gunay, M. (2008). Investigation of the Interaction between the Surface Quality and Rake Angle in Machining of AISI 1040 Steel. *Journal of Engineering and Natural Science*, *26*(2).

Guo, Y., M'Saoubi, R., & Chandrasekar, S. (2011). Control of Deformation Levels on Machined Surfaces. *CIRP Annals*, *60*(1), 137-140.

Heidari, M., & Yan, J. (2017). Fundamental Characteristics of Material Removal and Surface Formation in Diamond Turning Porous Carbon. *International Journal of Additive and Subtractive Materials Manufacturing*, *1*(1).

Image Processing and Analysis in Java - ImageJ. (2018). Retrieved 2023, from https://imagej.net/ij/index.html

Ipilakyaa, D. T., & Gundu, T. D. (2017). A Study on the Effect of Rake Angle and Feed Rate on Cutting Forces during Orthogonal Cutting. *European Journal of Advances in Engineering and Technology*.

Kaynak, Y., & Kitay, O. (2018). Porosity, Surface Quality, Microhardness and Microstructure of Selective Laser Melted 316L Stainless Steel Resulting from Finish Machining. *Journal of Manufacturing and Materials Procesing*, *36*(2), 1-14.

Kilchenstein, G. (2020). Cold Spray Technologies used for Repairs. (U. D.-M. (ODASD-MPP), Ed.) Joint Technology Exchange Group. Retrieved 2023

Koch, G. H., Brongers, M. P., Thompson, N. G., Virmani, Y. P., & Payer, J. H. (2002). Corrosion Costs and Preventive Strategies in the United States.

Kumar Ananda, R. K. (2017). A Study of The Machinability of Additively Manufactured Inconel 625. *Wichita State University, Department of Industrial, Systems, and Manufacturing Engineering.*

Nagakalyan, S., & Ramalinga Reddy, M. (2023). Experimental Investigation of Surface Roughness by Varying Single-Point Cutting Tool Geometry. *Advancements in Aeromechanical Materials for Manufacturing*.

Pandey, P. M., Reddy, N. V., & Dhande, S. G. (2003). Improvement of surface finish by staircase machining in fused deposition modeling. *Journal of Materials Processing Technology*, *132*(1-3).

Panzera, T. H., & Campos Rubio, J. C. (2005). A Survey on Ceramic Composites for Application in Porous Bearing. *18th International Conference of Mechanical Engineering*.

Rios, S. K., Hernandez, R. E., Llave, A. M., & Koubaa, A. (2013). Effects of Cutting Direction, Rake Angle, and

Depth of Cut on Cutting Forces and Surface Quality during Machining of Balsam Fir. *Journal of the Society of Wood Science and Technology*, *45*(2), 195-205.

Sample, C. M., Champagne, V. K., Nardi, A. T., & Lados, D. A. (2020). Factors Governing Static Properties and Fatigue, Fatigue Crack Growth, and Fracture Mechanisms in Cold Spray Alloys and Coatings/Repairs: A Review. *Additive Manufacturing*, *36*, 1-30.

Yin, S., Cavaliere, P., Aldwell, B., Jenkins, R., Liao, H., Li, W., & Lupoi, R. (2017). Cold Spray Additive Manufacturing and Repair: Fundamentals and Applications. *Journal of Thermal Spray Technology*, *21*, 1573-1584.

Zahiri, S. H., Fraser, D., Gulizia, S., & Jahedi, M. (2006). Effect of Processing Conditions on Porosity Formation in Cold Gas Dynamic Spraying of Copper. *Journal of Thermal Spray Technology*, *15*(3), 422-430.

Zuo, C., Meng, G., Zhou, X., & Liu, Q. (2022). Diamond Turning of Freeform Surfaces using Non-Zero Rake Angle Tools. *The International Journal of Advanced Manufacturing Technology*, *118*, 2265-2284.

Implementation and Evaluation of Curved Layer Fused Deposition Modeling

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Abstract

Fused Deposition Modeling (FDM) is an extrusion-based additive manufacturing (AM) process in which a thermoplastic material is extruded through a nozzle. Although it was initially developed for rapid prototyping, advances in the FDM technology have rapidly increased its range of applications. However, the FDM process has inherent disadvantages, such as poor surface finish, severe anisotropic mechanical properties, and increased build time for high-resolution parts. This is the result of the layer-by-layer manufacturing process. To remedy these issues, Curved Layer Fused Deposition Modeling (CLFDM) offers a new building paradigm for FDM in which the material is deposited in curved nonplanar layers. The purpose of this study is to implement a curved-layer toolpath generation algorithm and quantify the benefits of the curved layered methodology over traditional planar layers in printing thin-contoured parts.

Keywords: Prototyping, Additive Manufacturing, Curved Layers, Fused Deposition Modeling.

1. Introduction

Additive manufacturing (AM), formally known as rapid prototyping and more commonly known as 3D printing, is defined by ASTM F2792-12a as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies." The distinguishing principle of AM technology is its ability to fabricate parts directly from computer-aided design (CAD) information without tooling. Fused deposition modeling (FDM) is currently the most popular AM process, owing to the abundance of affordable and accessible machines. FDM has the advantage of utilizing a large variety of materials with varied mechanical properties. The ease of use, low cost, and community for open-source collaboration made it an attractive technology for hobbyists and professional engineers. FDM uses filament of thermoplastic build material with diameter ranging from 0.07 to 0.11 inches (1.75 to 2.85 millimeter). The filament is fed into a heated nozzle and extruded onto a flat substrate in a semi-solid state. The nozzle deposits material along a two-dimensional path to create a layer. Successive layers are stacked to create a three-dimensional object. More industrialized FDM machines feature a second nozzle to extrude the support material to assist in constructing overhangs in the model. However, this process has inherent disadvantages. Because of the layered structure, the printed parts approximate the original CAD model. This effect is known as stair stepping on a curved surface. The approximation error is most prevalent where the slopes are nearly horizontal. The severity of stair stepping can be minimized by using smaller layer heights. Very fine layer heights

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are typically available only on high-cost machines, and result in longer building times. Even with fine layers, the stair-stepping effect is visible to the naked eye. It can be completely removed by additional post-processing such as machining or the use of chemicals, although each additional step adds time and cost. In addition, the planar layer-by-layer manufacturing style results in anisotropy. The bonding strength between the layers is significantly lower than that of the continuous filament. This effect is amplified in thin-contoured parts, owing to the lack of superposition over the previous layer. This paper presents an application of curved layer printing to thin-contoured parts and provides a qualitative assessment of printed samples. The following section provides a review of the literature on curved-layer 3D printing. A description of the toolpath generation program and experimental settings are provided in Sections 3 and 4. Section 5 presents a quantitative assessment of the printed samples followed by statistical analysis of the results in Section 6. Research findings and concluding remarks are presented in Section 7.

2. Literature review

As early as 1994, adaptive slicing became the main strategy for reconciling the maximized part accuracy with the minimized part build time. Adaptive slicing uses an algorithm to analyze CAD models to determine the optimal layer height at a specific layer to maintain a predetermined tolerance. Layers with vertical or near-vertical slopes maintain larger layer heights with minimal approximation errors. Near-horizontal slopes require reduced layer heights and therefore achieve improved accuracy and surface finish. According to Suh and Wozny (1994), the increase in build time owing to smaller layers is balanced by the decrease in build time owing to larger layers. As reported by Sabourin et al. (1996), the adaptive layering method has experimentally achieved an overall surface finish equivalent to a uniform layer height of 0.005 inch (0.13 millimeter), but with a near 50% reduction in build time.

Klosterman et al. (1999) shifted the building paradigm by introducing curved layers. They modified a laminated-object machine to fabricate parts using curved layers. Their study focused on extruder path generation, in which two criteria were identified: the orientation of filaments and ideal bonding between adjacent deposition paths and the previous layer. Huang et al. (2008) integrated mechanical, electronic, and software systems to develop an AM machine capable of curved-layer printing. With this hardware, considerable strides were made in the curved layer deposition strategy, modeling, and evaluation. The slicing algorithm processes the STL file to output the final toolpath, including the support structure. Singamneni et al. (2012) use this method to construct several components. They reported an increase in the maximum compressive load of nearly 40% compared with that of the planar parts. Further developments incorporated curved layers into other printing strategies.

Huang and Singamnein (2015) explored the concept of integrating planar, adaptive, and curved layers into a single process referred to as “mixed-mode slicing.” The test parts were fabricated with uniformly curved layers of varying thicknesses. As reported by Patel et al. (2015), the CLFDM method is anticipated to increase strength, eliminate stair stepping, and even decrease print time. Figure 1 illustrates the effects of the planar and curved layers on the thin shell-like parts.

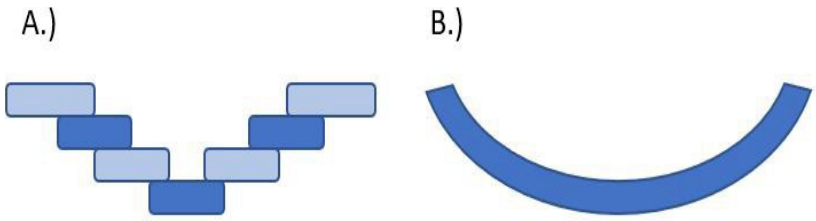

Figure 1. A) Illustration of planar layers, B) Illustration of curved layers

Ding et. al. (2015) explored multidirectional slicing for robotic wire-fed AM. A robotic wire-fed system allows material deposition across five axes, and can encompass exceptionally large build volumes. They used multidirectional slicing to eliminate support structures. The toolpath is rotated and translated into the coordinate system of the original component and ordered by its topology. However, they did not report the results of actual printing. Allen and Trask (2015) experimentally demonstrated CLFDM by using increasingly complex case studies. The toolpath was generated using a simplistic mathematical approach. A surface equation was used to populate an array of data points that represented an equally spaced grid on the X-Y plane of the printed part. This creates a vector field, in which the extruders sequentially follow an up-down and left-right rastering pattern.

Zhao et al. (2018) used a multidirectional slicing approach to print overhangs without the assistance of support structures, which is referred to as inclined-layer printing. This approach was developed for off-the-shelf, three-axis FDM printers. Like the strategy used by Ding et al. (2015), the objects were partitioned into separate regions based on the overhang. The printing direction was defined for each partition. All partitions were rotated to orient their respective printing directions to align with the z-axis and translated onto the print bed.

Khurana et al. (2019) proposed active-Z printing, which is another unique way to leverage nonplanar layering to improve mechanical properties. Two-dimensional parallel layers create high anisotropy in parts, which results in reduced mechanical properties along the z axis. Active-Z uses motion in all three axes simultaneously to print parts. They utilized open-source slicing software to produce the toolpaths. They concluded that the nonplanar layers exhibited an increase in strength and stiffness compared with the planar layered parts. Ahlers et al. (2019) introduced free downloadable open-source slicing software that can automatically generate G-code for CLFDM from an STL file.

Miciński et al. (2021) demonstrated the feasibility of building an add-on table to extend the printing capabilities of cartesian printers. The table provides the additional three degrees of freedom required for positioning the 3D printed parts. They used graphical programming in a G-code translator to create the toolpaths. Feng et al. (2021) proposed a modeling process for a five-axis printing machine. The machine consists of a printing head fixed on a delta-type manipulator and a rotary platform. They used conformal curved slicing to compute curved layers, and geodesic distances to extract equidistant toolpaths. This process eliminates the need for support structures (non-support printing) and prevents interference between the printing head and part by taking advantage of rotary printing. The test results of the five-axis printed samples indicated a 153% increase in failure strength compared to the three-axis printed samples. They reported that the surface roughness (Ra) decreased significantly from 42.09 to 18.31 mm with a 42.9% reduction in material consumption.

3. Experimental settings

A factorial experiment was designed to compare the strengths of two build styles (planar and curved). The factors considered were the build style (A), build material (B), and print speed (C). The model materials were polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). PLA and ABS were selected because they are the most commonly used materials for desktop FDM systems. The print speed was considered at 1.57 and 2.36 inch per second (40 and 60 millimeters per second). Eight test samples were printed in a random order, following factorial settings. A delta-style 3D printer was used to allow movement with equal acceleration and precision in the X, Y, and Z directions. The printer (FLSUN QQ-S Delta 3D printer) features a circular heated bed, a full metal frame, an auto-leveling procedure, and an E3D Titan extruder.

The test samples were modelled to represent a thin-contoured part. A contour was created using a mathematical model in the form Z = amplitude × sin (y2) + offset. An offset was applied to ensure that the full-support structure was printed underneath the part. The test samples had a footprint of 3 × 3 inches (76 × 76 mm) on a print bed. A layer height of 0.008 inch (0.2 millimeters) was used for all parts. Five layers were used resulting in a thickness of 0.04 inches (1.0 millimeter). An amplitude of 0.3 inch (7.6 millimeters) with an offset of 0.004 (0.1 millimeter) was used. Figure 2 shows samples of the test parts for both the curved and planar layers.

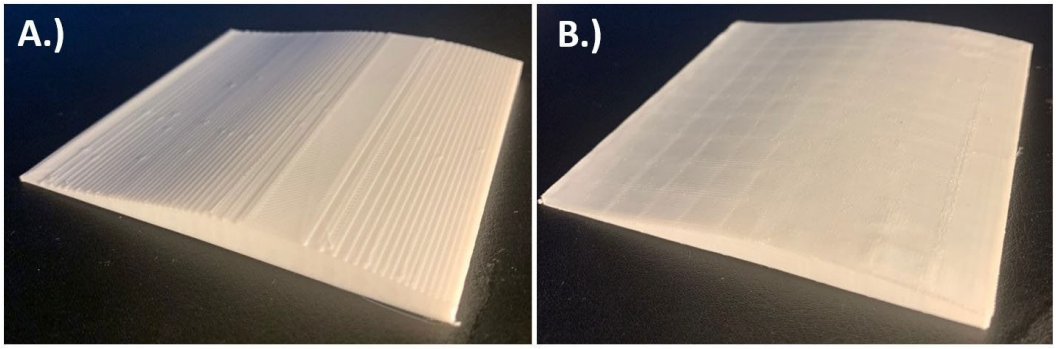

Figure 2. A) Planar layered test part, B) Curved layer test part

Because 3D printers cannot print on an empty space, a support structure is required beneath the curved layers. The structure was designed using the CATIA software (Dassault Systèmes, BM, version 5, 2020). A Python function was used to generate an ASC file with a two-dimensional array representing the X, Y, and Z values of the surface. The ASC file was loaded onto CATIA as a point cloud, and the surface was generated. This surface acted as the bottom of the curved layers and was therefore the top of the support structure. Two layers of small disks are added to the corners of the support structure to prevent warping. In addition, a raft was used to minimize warping. The support structure was printed using planar layers with a 15% dense infill. Four curved layers of the support material were deposited on top of the planar layers to provide a smooth curved substrate for the modeling material. A pause command was then incorporated into the G-code to swap the support material for the modeling material. Five curved layers of the modeling material were deposited. Polyvinyl alcohol (PVA) was used to produce a water-soluble support structure for curved layers. The planar layer parts used support structures made of model material. All the support structures, disks, and rafts were removed after printing.

4. Toolpath development

The mathematical approach utilized by Allen and Trask (2015) was adopted using Python programming language to produce the CLFDM test parts. All toolpaths generated in Python start with a simple surface equation, where the Z values are functions of X and Y. The surface equation represents the bottom surface of a printed part. A user-defined variable determines the size in millimeters, and the printed part takes on the print bed. A two-dimensional array was generated to store the Z values for the X and Y positions. This array acted as a point cloud that was used to generate toolpaths. The spacing of the X and Y values in the array corresponded to the width of the extrusion nozzle. The size of the array was calculated by dividing the size of the printed part by nozzle diameter. The generated toolpath travels from one point in the array to the next point. With all X, Y, and Z values contained in the array, the motion commands are simply "G01" commands, followed by changes in the X, Y, and Z values from the previous point. A loop was used to increment the indices in the array to generate motion commands. With conditional statements to recognize when the nozzle reached the sides of the part, the result was an up- and down-rastering deposition pattern. After the curved layer was completed, the Z values in the array were incremented by layer height. The following layer used a similar procedure but with a raster deposition pattern from side to side. The extrusion value was calculated by using the vector magnitude from the previous point. This represented the distance travelled from point to point. The volume conversion of the deposited bead along this path and volume of the filament in the extruder were calculated based on the extrusion value. The resulting G-code file generated by the program can be downloaded from https://bit.ly/302a3h9.

5. Results

The test parts were constructed and evaluated to achieve the research objectives. Several trial prints were constructed to verify the toolpath generation program. Both the planar and curved layers were printed without problems. The printing time for the curved layer parts was longer than that for the planar layer parts, owing to the support structure. Furthermore, the print time of the curved layered parts fluctuated slightly owing to manual material change. The curved layer parts were printed in approximately 3.5 hours each and the planar layered parts were printed in approximately 2 hours each.

The peak failure loads of the test samples were evaluated via a three-point bending test. An MTS test system with a 100-pound load cell was used. A custom test fixture was designed to hold the test samples. Figure 3 shows the full test setup of the MTS machine and the test fixture. The factor levels and the recorded measurements are listed in Table 1.

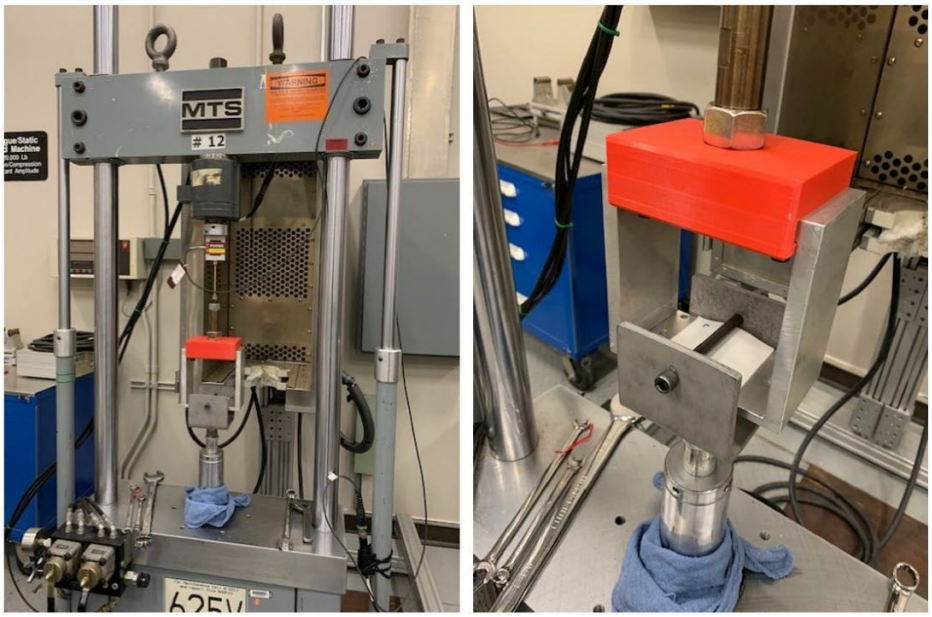

Figure 3. Peak failure test and custom fixture

Table 1. Factor levels and recorded measurements

RUN	STYLE (A)	MATERIAL (B)	PRINT SPEED (C)	PEAK FAILURE LOAD (lbf)
1	Curved	ABS	2.36	9.76
2	Curved	ABS	1.57	10.43
3	Curved	PLA	1.57	13.52
4	Planar	ABS	2.36	4.43
5	Planar	PLA	1.57	6.52
6	Curved	PLA	2.36	15.31
7	Planar	ABS	1.57	4.99
8	Planar	PLA	2.36	5.89

To evaluate surface roughness, two test samples were scanned using an optical 3D measurement system (Alicona G4 Infinite Focus). The surface roughness data in the direction perpendicular to the direction of extrusion were collected using a profile length of 0.2 inches (5 millimeters) and a cut-off wavelength of 0.3 inches (7.5 millimeters). Four measures of surface roughness were selected according to ASME B46.1 (2019). A summary of the reported measurements is presented in Table 2. As can be seen, using curved layer printing resulted in more than a 90% reduction in the surface roughness. The stair-stepping effects were eliminated.

Table 2. Summary of roughness measurements (in micrometers)

Measure	Planar	Curved	Definition
Ra	18.289	1.447	Average roughness
Rq	27.015	1.785	Root mean square roughness
Rt	143.791	10.388	Maximum peak to valley height
Rz	114.852	7.992	Mean peak to valley height

6. Statistical analysis

The statistical analysis of the peak failure load was conducted according to the procedure recommended by Montgomery (2019). The half-normal plot of the absolute effects shown in Figure 4 was constructed using Design-Expert software (Stat-Ease Inc. version 13, 2020). The plot indicates that both the build style (A) and material used (B) have significant effects on the average peak load. Print speed (C) had no significant effect on the average peak load.

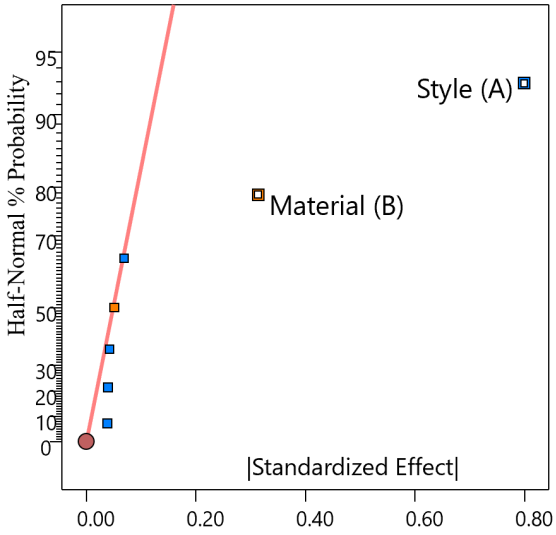

Figure 4. Half-Normal probability plot of the absolute effects

These results were confirmed using an analysis of variance (ANOVA). However, a diagnostic examination of the residuals suggested that log transformation was needed to stabilize the error variance. As shown in Table 3, the results indicated that both factors were statistically significant (P-values < 0.01). The effect plot of build style (A) shown in Figure 5 indicates that the maximum average peak load was obtained when the samples were constructed using the curved layer build style. Regardless of the build material, using the curved layer build style resulted in a 123% increase in average peak load. Figure 6 presents the effect of build material (B) and suggests that the maximum average peak load was obtained when the samples were constructed using PLA, as expected.

Table 3 Analysis of variance of Log (Peak load)

Source	Sum of Squares	df	Mean Square	F-value	p-value
Style (A)	1.29	1	1.29	255.03	< 0.0001
Material (B)	0.1991	1	0.1991	39.38	0.0015
Residual	0.0253	5	0.0051		
Total	1.51	7			

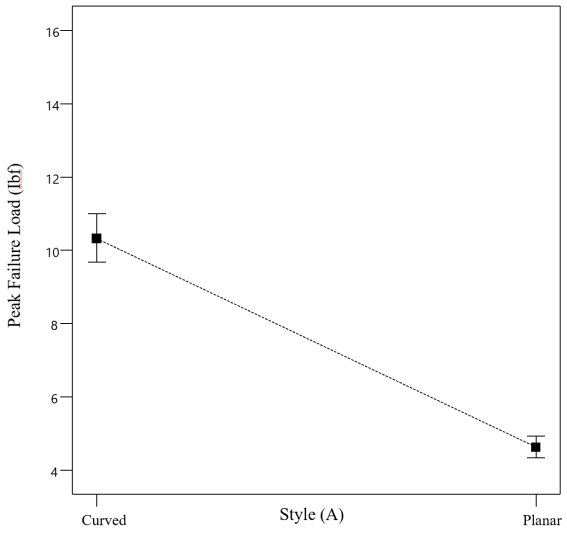

Figure 5. Effect plot of the build style (A)

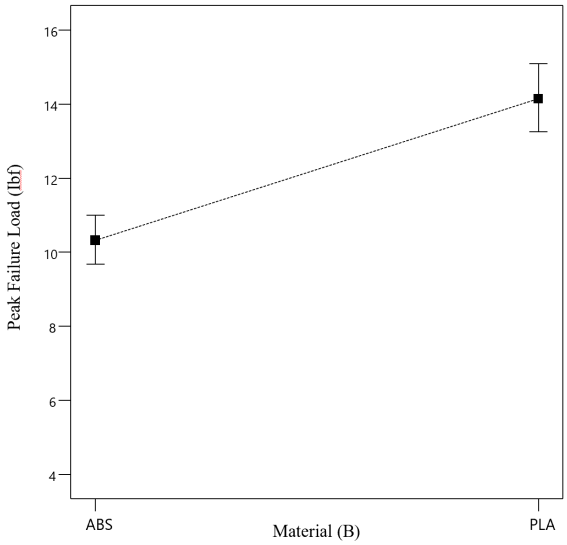

Figure 6. Effect plot of the build material (B)

7. Conclusions

This paper presents a quantitative evaluation of the benefits of using CLFDM to print thin-contoured parts. The toolpath generation program was written in Python. This program allows the user to define the surface equation and to generate a G-code file. Users can easily manipulate the size of the printed part, the layer thickness, speed, offset, temperature, nozzle size, extrusion multiplier, and retraction. In addition, the program generates another file containing a point cloud on the bottom surface of the curved layer. This file can be used to design a CAD file for the support structure underneath curved layers.

The curved layer test parts were found to have a superior surface finish compared with the planar layer samples. Furthermore, the strength of the test samples increased significantly. The results of the three-point bending test revealed an increase in average failure load for both the PLA and ABS samples. The increase in average load was as high as 2.2 times its planar layered counterpart. These authors are developing another program for the CLFDM of a five-axis machine to allow the printing of parts with substantial contours. A new motion system, extrusion system, and deposition strategy are proposed to provide new opportunities for CLFDM.

8. References

Ahlers, D., Wasserfall, F., Hendrich, N., & Zhang, J. (2019, August). 3D printing of nonplanar layers for smooth surface generation. In *2019 IEEE 15th international conference on automation science and engineering (CASE)* (pp. 1737-1743). IEEE.

Allen, R. J., & Trask, R. S. (2015). An experimental demonstration of effective Curved Layer Fused Filament Fabrication utilising a parallel deposition robot. *Additive Manufacturing*, *8*, 78-87.

American Society of Mechanical Engineers. (2019). ASME B46. 1-2009. Surface texture (surface roughness, waviness and lay). New York, NY: ASME.

ASTM F2792-12a. (2013). Standard terminology for additive manufacturing technologies.

Ding, D., Pan, Z., Cuiuri, D., Li, H., Larkin, N., & Van Duin, S. (2015). Multi-direction slicing of STL models for robotic wire-feed additive manufacturing. In *2015 International Solid Freeform Fabrication Symposium*. University of Texas at Austin.

Feng, X., Cui, B., Liu, Y., Li, L., Shi, X., & Zhang, X. (2021). Curved-layered material extrusion modeling for thin-walled parts by a 5-axis machine. *Rapid Prototyping Journal*, *27*(7), 1378-1387.

Huang B., Singamneni S., and Diegel O., (2008). Construction of a curved layer rapid prototyping system: integrating mechanical, electronic and software engineering. *In the 15th International Conference on Mechatronics and Machine Vision in Practice*, IEEE, pp. 599–603.

Khurana J., Dinda S., and Simpson T., (2019). Active-z printing: A new approach to increasing 3d printed part strength. In *Solid Freeform Fabrication Symposium*, pp. 1627–1644.

Klosterman D., Chartoff R., Osborne R., Graves G., Lightman A., (1999). Development of a curved layer LOM process for monolithic ceramics and ceramic matrix composites. *Rapid Prototyping Journal*, Vol. *5*, No. 2, pp. 61-71.

Huang, B. and Singamneni, S.B. (2015), "Curved Layer Adaptive Slicing (CLAS) for fused deposition modelling", *Rapid Prototyping Journal*, Vol. 21, No. 4, pp. 354-367.

Montgomery C (2019), Design and Analysis of Experiments, 10th ed., John Wiley & Sons, Inc.

Miciński, P., Bryła, J., and Martowicz, A., (2021), "Multi-axis Fused Deposition Modeling using parallel manipulator integrated with a Cartesian 3D printer," *International Journal of Multiphysics*, Vol. 15, No. 3, pp. 251-263.

Patel Y., Kshattriya A., Singamneni S. B., and Choudhury R., (2015). Application of curved layer manufacturing for preservation of randomly located minute critical surface features in rapid prototyping. *Rapid Prototyping Journal*, Vol. 21, No. 6, pp. 725-734.

Sabourin E., Houser S., and Bøhn J. H., (1996). Adaptive slicing using stepwise uniform refinement. *Rapid Prototyping Journal*, Vol. *2*, No. 4, pp. 20-26.

Singamneni S., Roychoudhury A., Diegel O., and Huang B., (2012). Modeling and evaluation of curved layer fused deposition. *Journal of Materials Processing Technology*, Vol. 212, No. 1, pp. 27–35.

Suh, Y. S., and Wozny, M. J., (1994). Adaptive slicing of solid freeform fabri-cation processes, *1994 International Solid Freeform Fabrication Symposium,* pp. 404-411.

Zhao H., He Y., Fu J., and Qiu J., (2018). Inclined layer printing for fused deposition modeling without assisted supporting structure. *Robotics and Computer-Integrated Manufacturing*, Vol. *51*, pp. 1–13.

Infrastructure and Internet Inclusiveness as Determinants of e-commerce Expansion

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Abstract

Due to the rapidly increasing number of people around the world with Internet access, the web's global reach is affecting the growth and development of the world economy. At the macro or national level, research has been conducted to examine the growth of E-Business in Developing nations and cultural determinants of e-commerce adoption at a national level and in relation to the digital divide. In a previous study the authors focused on four particular drivers of this expansion: (1) the rapid expansion of availability of the Internet to an ever-growing number of people, (2) the increased affordability of Internet access, as technology and connection costs have plummeted, (3) the ever-widening relevance of Internet resources (function, local language access, etc.) to broad swaths of the world's population, and (4) the readiness of a nation (infrastructure, cultural acceptance) to adopt E-Commerce. Results of this study showed that, among other things, the relative importance of the "Price" and "Competitive Environment" sub-components suggest that e-commerce thrives best under a regime of inexpensive Internet connectivity available from a variety of competing suppliers. The current study expands on this analysis by examining the fifty-seven directly measurable dependent variables which constitute the 3i Index to assess which variables are the most significant as determinants of e-commerce expansion.

Keywords: E-Commerce, Internet Infrastructure, Internet Inclusiveness, Digital Divide

1. Introduction

The global reach of the Web has been greatly influenced by the increasing number of people with Internet access worldwide, and its impact on the growth and development of the world economy cannot be understated. Extensive research has been conducted to understand the growth of E-Business in developing nations and the cultural determinants of e-commerce adoption at a national level, particularly in the context of the digital divide. Previous studies have identified four key drivers of this expansion, including the availability and affordability of Internet access, the relevance of Internet resources to diverse populations, and the readiness of a nation to adopt e-commerce in terms of infrastructure and cultural acceptance.

To further investigate these drivers, this research utilizes the Inclusive Internet Index (3i) (Economist Impact, 2023), a multi-dimensional measure of the electronic infrastructure of various nations, commissioned by Facebook and covering 100 countries representing a significant portion of the world's population and global GDP. The 3i Index, based on input from over 5,000 respondents, benchmarks

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countries on the availability, affordability, relevance, and readiness of people to use the Internet. In this study, the authors examine the fifty-seven directly measurable variables that constitute the 3i Index to determine which variables are the most significant as determinants of e-commerce expansion.

The findings of this research shed light on the relative importance of different variables in driving e-commerce growth. Specifically, the study delves into sub-components such as "Price" and "Competitive Environment" to highlight the significance of inexpensive Internet connectivity and competition among suppliers in fostering a conducive environment for E-Commerce. The results of this study contribute to the understanding of the complex relationship between Internet infrastructure and e-commerce expansion, providing valuable insights for policymakers, businesses, and researchers alike.

2. Literature Review

Our research centered upon the following question: What is the relationship, at a national level, between the functionality of Internet infrastructure and the growth of E-Commerce. The idea that this relationship does exist is not a matter of conjecture in this study. We assume that there is a relationship between these variables such that better Internet infrastructure should facilitate e-commerce revenue growth (Dumičić, et al., 2018; Waseem, et al., 2019). One of the bases of this assumption is shown in Figure 1 which depicts the results of the 2019 Network Readiness Index analysis. This part of the analysis shows a clear relationship between the Network Readiness Index (NRI) and GDP Per Capita. This index, developed by the World Information Technology and Services Alliance was created to “provide, for the first time, a holistic framework for assessing the multi-faceted impact of ICT on society and the development of nations.” Another index that attempts to measure the use of technology is the Technology Readiness Index (TRI 2.0), a 16-item scale designed to measure people’s propensity to embrace and use cutting-edge technologies (Parasuraman and Colby, 2014). This tool is designed to be used at the micro level for the purposes of customer segmentation with respect to technology readiness.

A variety of research studies have approached the global aspects of e-commerce at the micro level, dealing with firms and industries in terms of issues such as consumer behavior (Shiu-Li, et al., 2019), socialization (Xintian & Xiangdong, 2019), technology use, business factors (Gorla, et al., 2015), e-commerce intensity (Kuresova & Eger, 2017) and web site globalization (Augustine, et al., 2008). At the macro or national level, research has been done to examine e-commerce and economic growth (Hibner, 2012), the growth of e-commerce in Developing nations (Dumičić, et al., 2018), and cultural determinants of e-commerce adoption at a national level and in relationship to the digital divide (Makame, et al., 2014).

Our previous research extended this line of inquiry. Specifically, we examined the relationship between e-commerce revenue and infrastructure at the national level using a multifaceted assessment of Internet participation, the Inclusive Internet Index (3i Index).

2.1. The Inclusive Internet Index

According to Business Standard (2020), the Inclusive Internet Index “benchmarks countries on the internet's availability, affordability, relevance, and the readiness of people to use it. The annual report is commissioned by Facebook. In its fifth year, the index covered 100 countries, representing 99% of the world's population and 97% of global GDP.” This index represents a multi-dimensional measure of the

electronic infrastructure of various nations. The 3i Index, which polled more than 5,000 respondents from 100 countries, was developed as an approach to measure the effectiveness of existing Internet Infrastructures.

The overall index score is produced based on scores assigned for the Availability, Affordability, Relevance and Readiness categories. The Availability category "examines the quality and breadth of available infrastructure required for access and levels of Internet usage". Affordability "examines the cost of access relative to income and the level of competition in the Internet marketplace." Relevance "examines the existence and extent of local language content and relevant content" and Readiness "examines the capacity to access the Internet, including skills, cultural acceptance, and supporting policy." (Economist Impact, 2023)

These four indexes are based upon both measurable values (such as the number of Internet users or Smartphone cost) and assessed perceptions on how the Internet use impacts individuals (such as the availability of basic information in the local language or social level of trust in online privacy). Each of the four main categories is further broken down into sub-categories. For example, Availability is expressed as a combination of Usage, Quality, Infrastructure and Access to Electricity. Each sub-category, in turn, is composed of various baseline statistics. As an example, the Readiness sub-category of Literacy consists of the following measures: Level of Literacy, Educational Attainment, Support for digital literacy and Level of web accessibility.

2.2. Previous Research

Our previous research examined the basic relationship between e-commerce and infrastructure at the national level (Augustine, Rasp, and Nguyen, 2020). In this paper we examined the relative importance of the four drivers of e-commerce adoption and expansion identified in the Inclusive Internet Index as driving the expansion of Electronic Commerce. These drivers are (1) the rapid expansion of availability of the Internet to an ever-growing number of persons, (2) the increased affordability of Internet access, as technology and connection costs have plummeted, (3) the ever-widening relevance of Internet resources (function, local language access, etc.) to broad swaths of the world's population, and (4) the readiness of a nation (infrastructure, cultural acceptance) to adopt E-Commerce.

This analysis examined the relationship of eleven sub-component variables in the Index (Usage, Quality, Infrastructure, Electricity, Price, Competitive Environment, Local Content, Relevant Content, Literacy, Trust and Safety, and Policy), with (log) e-commerce Revenue per Capita. Correlations between each subcomponent, and Log Revenue per Capita generally show moderate to strong correlations (ranging from .897 for Usage to .497 for Policy. The exception is the Trust & Safety variable, which is essentially uncorrelated with Log Revenue per Capita. The t-scores and p-values for all the subcomponents were highly significant except for the "Trust and Safety" variable. The results of the regression of the eleven sub-component (dependent) variables to (log) Revenue per Capita shows that four of the variables (Usage, Price, Competitive Environment and Literacy) were significant based on their (one-tailed) p-values.

The number of dependent variables and the multicollinearity between the variables, combined with

the preliminary and exploratory nature of the research, convinced us that it was premature to posit definitive interpretation of these results. Nevertheless, the findings did offer several insights, and suggest various lines of further inquiry.

That the "Usage" variable is the sub-component most highly correlated with E-commerce revenue, and with most significant contribution in the multiple regression analysis, suggests that it is the prime driver of the E-commerce economic boom. This makes good sense – for E-commerce even to exist, individuals must, of necessity, be using the Internet. It also suggests a policy priority: that simply getting people connected is the first order of business, in terms of fostering E-commerce growth. We further noted that, in the multiple regression, the "Infrastructure" and "Electricity" variables were not significant once other factors were considered. This stands rather in contrast to the "if you build it, they will come" mantra of some development theorists. Here, it seems, simply having the structures in place for e-commerce to exist is not enough to drive revenue; the populace must be moved to "Usage" of the Internet resource. The issues in developmental economics suggested here are well worth further study.

Relative importance of the "Price" and "Competitive Environment" sub-components suggested other policy priorities as well. The implication is that e-commerce thrives best under a regime of inexpensive Internet connectivity available from a variety of competing suppliers. These issues appear to trump more nationalistic concerns, such as the availability of locally sourced or culturally relevant content. Matters of localism versus globalism are becoming increasingly prominent in contemporary economic policy debate. Computer professionals likewise deal with the dynamics of local control versus the worldwide scope of the Internet. These matters are worthy of much greater study, but this finding does lean toward the global-competitive rather than local-protectionist approach.

It was clear to us that three of the four first-level variables (Availability, Affordability and Readiness) contribute to the economic value of e-commerce at a national level when expressed per capita. It appears that there is a significant relationship between the Overall 3i Index measure and Per Capita e-commerce revenue. It also appears that there is a basic threshold needed, in each of the four first-level component areas, before meaningful economic growth for e-commerce occurs. This phenomenon also occurs for each of the four constituent measures. It appears that all four first-level components are highly significant predictors of economic activity. However, there is multicollinearity and Relevance does not add significant explanatory power, once the other three variables are in the model.

2.3. Overview of the Current Research

The current study expands on this analysis by examining only those variables which constitute the 3i Index that are directly measurable. This led to a reduction of the number of dependent variables within the four top-level categories to fifty-seven. The breakdown of these variables is as follows: Availability – 21, Readiness – 17, Relevance – 11, and Affordability 7. The study uses these variables to develop a more appropriate assessment as to which variables are the most significant as determinants of e-commerce expansion.

3. Results

Analysis on this data was performed using correlation and regression analysis. The dependent variable in this analysis is the Log of Per Capita e-commerce measured in US dollars. We examined the

variables in each of the top-level categories independently. Our analysis yields the following results.

3.1. Availability

(Log) Ecommerce per capita is highly correlated with the "Availability" measure of the 3i index. "Availability" explains 78.7% (r-square) of variation in the Ecommerce variable. There are four second-level variables in this category, Usage, Quality, Infrastructure, and Electricity. All four of these predictors are highly correlated with per capita E-Commerce. However, they are also highly correlated with one another, indicating a high degree of multicollinearity. The use of One-tailed p-values are in order, as we have a priori reason to believe in a positive relation for all variables. In this case, "Usage" is the only statistically significant predictor of per capita E-Commerce. However, other variables are marginally significant. That is, the "Usage" variable captures the greatest explanatory power. Once it is in the model, the other variables contribute only marginally. These four second-level variables can be represented by twenty-two third-level variables.

This analysis suggests that Internet Users and Fixed-line broadband subscribers are the variables that matter most in contributing to per capita E-Commerce. However, all the variables are statistically significant. It seems that getting users connected is the most important factor in the expansion of E-Commerce. It is possible that some of the results may be a result of proxies for national wealth. So, for example, rural electricity access matters more than urban, but it is the wealthy nations that feature high rural electric access.

3.2. Readiness

As noted in our initial study, (Log) Ecommerce per capita is correlated with the "Readiness" measure of the 3i index. "Readiness" explains 48.4% (r-square) of the variation in the Ecommerce variable. This is the lowest of the four top-level categories. But it's still exceedingly statistically significant. There are three second-level component variables that compose the Readiness category, Literacy, Trust and Safety, and Policy. The regression analysis of these variables indicates that only the Literacy category is significantly related to per capita E-Commerce. The analysis of the third-level component variables (Level of literacy, Educational Attainment, Trust in online privacy, Trust in Government websites and apps, Trust in Non-governmental websites and apps, Trust in information from social media, and e-commerce safety) shows only one variable “Educational Attainment” (measured by average years of schooling of the population) to be statistically significant. It seems that the more education people have, the more Ecommerce there is. This is not particularly surprising - education is a 'wealth' measure. The results of this analysis are shown in Table 1.

Table 1. Analysis of Third-Level Readiness Variables

	Coeff.	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.0425	0.3145	0.1350	0.8930	-0.5850	0.6700
4.1.1) Level of literacy	0.0031	0.0044	0.6991	0.4869	-0.0058	0.0120
4.1.2) Educational attainment	0.0244	0.0042	5.8232	0.0000	0.0160	0.0327
4.2.2) Trust in online privacy	0.0020	0.0034	0.5919	0.5558	-0.0048	0.0088
4.2.3) Trust in Government websites and apps	0.0051	0.0039	1.3115	0.1941	-0.0026	0.0128
4.2.4) Trust in Non-government websites and apps	-0.0082	0.0067	-1.2245	0.2249	-0.0216	0.0052
4.2.5) Trust in information from social media	-0.0005	0.0051	-0.0953	0.9243	-0.0107	0.0098
4.2.6) e-Commerce safety	0.0024	0.0033	0.7167	0.4760	-0.0042	0.0089

3.3. Relevance

(Log) Ecommerce per capita is correlated with the "Relevance" measure of the 3i index. "Relevance" explains 55.5% (r-square) of the variation in the Ecommerce variable. Once again, it isn't as high as Availability, but is still exceedingly significant. For the Relevance category, there are two second-level variables, Local Content and Relevant Content. Here, again, One-tailed p-values are in order, as we have an a priori reason to believe in a positive relation for all variables. Both variables are statistically significant. It appears that the more local content there is, and the more relevant content there is, then the more e-commerce there is. Not especially surprising, since this is correlation, not causation. What may be interesting is the development cycle here: Perhaps this is simply reflecting robust and broad-based development of the national internet ecology (organic growth of the Web in all aspects of national culture). The analysis of the third-level variables (Availability of local news in local languages, Concentration of websites using country-level domains, Availability of e-Government services in the local language, e-Finance content, Value of e-finance, e-Health content, Value of e-health, e-Entertainment usage, e-Commerce content, Value of e-Commerce, and Open data policies) reveals Only one statistically significant variable, "e-Commerce content." This variable "seeks to measure the availability - and extent of - electronic commerce … in the country" and is based on a B2C E-commerce index developed by a U.N. agency (UNCTAD). Note that the "Value of e-Commerce" variable is NOT at all significant. Data value based upon a survey ("How often do you purchase goods via the internet?") so it's a frequency measure not a value measure. The results of this analysis are shown in Table 2.

Table 2. Analysis of Third-Level Relevance Variables

	Coeff.	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.8069	0.5296	1.5236	0.1320	-0.2508	1.8646
3.1.1) Availability of local news in local languages	-0.0048	0.0059	-0.8067	0.4230	-0.0166	0.0070
3.1.2) Concentration of websites using country-level domains	-0.0006	0.0013	-0.4535	0.6520	-0.0031	0.0019
3.1.3) Availability of e-Government services in the local language	0.0015	0.0017	0.8854	0.3790	-0.0019	0.0050
3.2.1) e-Finance content	-0.0031	0.0025	-1.2397	0.2200	-0.0080	0.0019
3.2.2) Value of e-finance	-0.0011	0.0024	-0.4548	0.6510	-0.0058	0.0036
3.2.3) e-Health content	0.0014	0.0022	0.6211	0.5370	-0.0030	0.0057
3.2.4) Value of e-health	-0.0017	0.0028	-0.5911	0.5570	-0.0073	0.0039
3.2.5) e-Entertainment usage	0.0039	0.0035	1.1019	0.2750	-0.0032	0.0109
3.2.6) e-Commerce content	0.0247	0.0028	8.9457	0.0000	0.0192	0.0303
3.2.7) Value of e-Commerce	-0.0015	0.0037	-0.3994	0.6910	-0.0088	0.0059
3.2.8) Open data policies	0.0015	0.0012	1.2289	0.2240	-0.0009	0.0039

3.4. Affordability

(Log) Ecommerce per capita is correlated with the "Affordability" measure of the 3i index. "Affordability" explains 56.2% (r-square) of the variation in the Ecommerce variable. This isn't as high as Availability - but is still exceedingly significant. There are only two second-level variables associated with Affordability (Price and Competitive environment). One-tailed p-values are used here, as we have an a priori reason to believe in a positive relation for all variables. We see an interesting result here. The "Price" component of Affordability is what's driving things here; "Competitive Environment" is not at all significant (and hence not particularly relevant). This would seem to argue against a strong influence of free markets. However, if low prices are driven by government subsidies, this may not be sustainable and may not be economically efficient. Third-level variables are Smartphone cost (handset), Mobile

phone cost (prepaid tariff), 2.1.3) Mobile phone cost (postpaid tariff), 2.1.4) Fixed-line monthly broadband cost, 2.2.1) Average revenue per user (ARPU, annualized), 2.2.2) Wireless operators' market share, and Broadband operators' market share). These variables can be classified as either consumer costs or provider measures. We have not used one-tailed p-values here, as not clear there's an a priori reason to presume a positive (or negative) slope. In the case of these variables, it is not intuitively obvious why any of these variables might 'matter.' The only two that are statistically significant are 'Smartphone cost' and 'Average revenue per user'. Smartphone cost' has a positive impact on per capita e-commerce revenue which may indicate that in places where individuals buy more expensive smartphones, they may also buy more e-commerce goods. This may simply indicate that wealthier places have more disposable income, and more of it is spent online. Finally, the 'Average revenue per user' displays an inverse relationship with per capita e-commerce spending. This variable (per the data description given in the data source) is overall consumer spending on mobile services (both pre-paid and post-paid). Along with the previous result, this seems to suggest that high-end phones along with cheap cost of usage drives per capita e-commerce spending. The results of this analysis are shown in Table 3.

Table 3. Analysis of Third-Level Affordability Variables

	Coeff	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.2513	1.1498	-1.0883	0.2802	-3.5451	1.0424
2.1.1) Smartphone cost (handset)	0.0197	0.0035	5.5943	0.0000	0.0127	0.0267
2.1.2) Mobile phone cost (prepaid tariff)	0.0247	0.0173	1.4253	0.1586	-0.0099	0.0592
2.1.3) Mobile phone cost (postpaid tariff)	-0.0025	0.0093	-0.2710	0.7872	-0.0211	0.0161
2.1.4) Fixed-line monthly broadband cost	0.0051	0.0122	0.4171	0.6779	-0.0193	0.0295
2.2.1) Average revenue per user (ARPU, annualized)	-0.0080	0.0031	-2.5887	0.0117	-0.0141	-0.0018
2.2.2) Wireless operators' market share	-0.0023	0.0039	-0.5991	0.5510	-0.0101	0.0054
2.2.3) Broadband operators' market share	0.0034	0.0023	1.5102	0.1356	-0.0011	0.0079

4. Conclusions

Out of a total of fifty-seven third-level predictor variables analyzed in this study, only twenty-six had a statistically significant effect on per capita e-commerce spending. Of these, twenty-two were Availability measures, followed by two Affordability, and one each in the Readiness and Relevance categories. The coefficient of determination (adjusted R2) for the level-one categories was .906 for Availability, .786 for Affordability, .714 for Readiness, and .549 for Relevance. The analysis of Availability suggests that Internet Users and Fixed-line broadband subscribers are the variables that matter most in contributing to per capita E-Commerce, suggesting that ensuring that users are connected is the most important factor in the expansion of E-Commerce. The analysis of the third-level component variables of the Readiness category shows only one variable “Educational Attainment” (measured by average years of schooling of the population) to be statistically significant. The conclusion here is that the education-wealth correlation is important as an e-commerce driver. The "Price" component of Affordability seems to be the major factor influencing per capita e-commerce spending. What is not clear is the effect of government subsidies. Finally, the analysis of the third-level Relevance variables reveals only one statistically significant variable, "e-Commerce content." This variable "seeks to measure

the availability - and extent of - electronic commerce … in the country" so it's significance is not surprising.

5. References

Adam, I. O., Alhassan, M. D., & Afriyie, Y. (2020). What drives global b2c e-commerce? an analysis of the effect of ICT access, human resource development and regulatory environment. *Technology Analysis & Strategic Management*, *32*(7), 835–850.

Ahi, A. A., Sinkovics, N., & Sinkovics, R. R. (2023). e-commerce Policy and The Global Economy: A Path to More Inclusive Development*? Management International Review*, *63*(1), 27–56. https://doi.Org/10.1007/S11575-022-00490-1

Augustine, F., Rasp, J., & Nguyen, G. (2020). Infrastructure, Internet Inclusiveness and E-Commerce: An Exploratory Study, *Issues in Information Systems*, *21*(3), pp. 117-125, 2020

Augustine, F., Surynt T., & Jens, W. (2008). Global Readiness of E-Business Web Sites: An Industry Perspective, E-*Business Review*, *8*(1).

Dumičić, K., Bonić, I. S., & Žmuk, B. (2018). Statistical analysis of the development indicators' impacts on E-commerce of individuals in selected european countries. *Nase Gospodarstvo*: NG, *64*(2), 15-24.

The Inclusive Internet Index. (2023). *Economist Impact*: Updated for 2022, https://impact.economist.com/projects/inclusive-internet-index/.

Gorla, N. Chiravuri, A. and R. Chinta. (2015). Business to Business e-commerce Adoption: An Empirical Investigation of Business Factors, *Information Systems Frontiers*, *19*:645-667

Hibner, J. (2012). The development of an information society and electronic commerce in the European union in the context of selected documents of the EU and international organisations. *Comparative Economic Research*, *15*(1).

Kunešová, H., & Eger, L. (2017). Evaluation and Comparison of B2C e-commerce Intensity in EU Member States. E+M *Ekonomie a Management*, *20*(4), 151-167.

Makame, W., Kang, J., & Park, S. (2014). Factors influencing electronic commerce adoption in developing countries: The case of Tanzania. *South African Journal of Business Management*, *45*(2), 83-96.

Parasuraman, A. & Colby, C. (2014). An Updated and Streamlined Technology Readiness Index: TRI 2.0. *Journal of Service Research*. *18*(1), pp. 59-74.

Shiu-Li, H., & Ya-Chu, C. (2019). Cross-border e-commerce: Consumers' intention to shop on foreign websites. *Internet Research*, *29*(6), 1256-1279.

Waseem, A., Rashid, Y., Warraich, M., Sadiq, I., & Shaukat, Z. (2019). Factors Affecting e-commerce Potential of Any Country Using Multiple Regression Analysis. *Journal of Internet Banking and Commerce; Ottawa*, *14*(3), pp. 1-28.

Xintian, W., & Xiangdong, W. (2019). Socialization, traffic distribution and E-commerce trends: An interpretation of the "pinduoduo" phenomenon. *China Economist*, *14*(6), 56-72.

How to Conduct a Case Study: A Guide for Novice Researchers

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Abstract

Case study research has been gaining popularity due to its valuable capacity to provide rich, context-specific data as well as understanding of difficult circumstances. This is demonstrated by the fact that it has been utilized more frequently in recent research that has been published. This popularity may be attributed to the fact that case study research is able to deliver rich information about the case of study. This article presents a brief overview of the literature review that was conducted on the qualitative case-study methodology. It might serve as a quick reference tool for novice researchers who are intrigued about pursuing case studies. In this article, a brief historical overview of the evolution of the case study as a significant qualitative approach is demonstrated in connection to the pioneers of this type of research approach, namely Robert Yin, Robert Stake, and Sharan Merriam. The article additionally addresses the significance of the case study. The paper focuses on the types of case studies and basic recommendations that novice researchers may apply to systemically examine the underlying issues, patterns, or dynamics of a particular subject or case using a holistic approach. In light of the fact that case studies usually concentrate on specific instances, the article advises rookie investigators not to generalize the findings of case studies. In this article, numerous characteristics of case studies are examined, with a focus on its use as a separate qualitative inquiry and research approach.

Keywords: single-case study, multiple-case study, qualitative research, transferability.

1. Introduction

There are numerous interpretations of case studies in the literature. A case study is a research methodology in which the case is constrained by time and activity (Creswell, 2014). According to Yin (2009), "a case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 18). On the other hand, Stake (2000) states that a "case study is not a methodological choice but a choice of what to be studied (p. 435)". Stake refers to any study on any topic that uses any method as a case study. A case study, according to Merriam (1998), is a mode of inquiry that uses a variety of data gathering procedures to obtain in-depth information on an event, activity, community, or individual. "A case study is an in-depth description and analysis of a bounded system" (Merriam & Tisdell, 2015, p. 37).

2. Historical context

The case study emerged as a qualitative method in Charles Darwin's biography in the early

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nineteenth century (Stewart, 2014). Early case study research, according to Stewart, dates from the 1920s to the 1950s. The Chicago School of Psychology conducted the majority of the case study research. A new era of case studies arose at the same time as grounded theory (Glaser & Strauss, 1967). Case study research began in the early nineteenth century, encompassing several disciplines such as history, psychology, sociology, and anthropology, and eventually expanded to include a search for detailed and lengthy investigations of individuals and cultures in the discipline of ethnography (Merriam, 1998; Stewart, 2014). The case study approach was used in natural settings to investigate people's lives, experiences, and how those experiences affected their environment (Merriam, 2009). From the 1940s to the 1970s, quantitative approaches and experimental designs dominated, according to Merriam (2009). In quantitative studies, the case study was also employed as a descriptive research technique (Merriam, 2009; Stewart, 2014). In the 1970s, case studies were originally utilized in educational research to evaluate curriculum designs and drive the process of educational innovation (Merriam, 2009; Stake, 1995). During the 1980s and 1990s, case study research became prevalent in political science.

The most well-known case study methodologists in the realm of case study methodology are Robert Yin, Robert Stake, and Sharan Merriam. Robert Yin underlined the significance of a methodical and concise case study design as a thorough procedure with a strong emphasis on each step of the investigation. Yin defined four quality criteria for any case study design: concept validity, internal validity, external validity, and reliability. Yin is considered a contemporary figure who has significantly contributed to the understanding and application of the case study approach. His book "*Case Study Research: Design and Methods*" is widely used as a guide for researchers. The book examines the case study design and procedures, as well as why it is critical to employ it as a research approach in the social sciences. In addition, it offers “few guides on how to start a case study, analyze the data, or even minimize the problems of composing the case study report” (Yin, 2002, p. 3).

Robert Stake, an educational psychologist, was another significant addition to the area of case study. To guide the research strategy, Stake approached the case study from a constructivist and existentialist perspective. In contrast to Yin, Stake adopted a flexible design, which allowed the researcher to make adjustments even during the post-design period of the study. Because of Stake's interest in establishing evaluation program methods in the field of education, an emphasis on an inductive and holistic study of the case was placed. Stake’s The Art of Case Study Research is a fantastic resource for researchers whose questions can be answered with a qualitative case study method. Stake’s book describes the “naturalistic, holistic, ethnographic, phenomenological, and biographic research methods” (Stake, 1995, p. xi) as the interpretive orientation of the study case approach.

Sharan Merriam, the case study approach's third major contributor, expanded on the work of both Stake and Yin. Merriam employed Yin's well-structured case study design as well as Stake's rendition's four research quality standards. Merriam and Yin hold opposing views to Stake’s about validity and trustworthiness. Merriam, on the other hand, encounters Stake via her research lens as a constructivist who believes that reality is relative and subjective to everyone's unique life experience. Merriam's Qualitative Research and Case Study Applications in Education is a work of art that demonstrates Merriam's vision as well as the stages involved in conducting a case study. Merriam’s book debunks the

myth of the case study in qualitative research by explaining “what constitutes a case study, how it differs from other qualitative research methods, and when it is most appropriate to use it” (Merriam, 1998, p. 19).

It's important to note that the use of case studies has evolved over time, and many researchers in various fields have contributed to its development and refinement. The pioneers mentioned here represent just a few recent key figures associated with the early adoption and popularization of the case study method in their respective disciplines. One of the early pioneers of the case study method is often considered to be Frederic Play, a 19th-century sociologist. However, the case study approach gained prominence in the social sciences through the works of other scholars, such as Robert Stake, Robert Yin, and Sharan Merriam.

3. Types of case studies

Once the researcher has determined that a qualitative case study is the best way to answer the research question and understand the phenomenon under examination, he or she must choose a specific style of case study. Case studies are classified into two types: single-case studies and multiple-case studies (Stake, 1995; Yin, 2003). Case studies can be classified based on the purpose of the analysis (Creswell, 2014). According to Yin (2003), case studies are classified into three types based on their purpose: explanatory, exploratory, and descriptive. Yin (2003), for example, suggests utilizing an explanatory case study when seeking to explain a phenomenon that cannot be investigated by surveys or experimental investigations. For research with unclear outcomes, an exploratory case study may be preferred. A descriptive case study, according to Yin (2014), is one in which the investigator describes the relationship between the phenomenon and its real-life situation. A multiple-case study, as indicated by Yin, should be conducted when the purpose of the study is to compare the similarities and differences across selected examples (Baxter & Jack, 2008; Yin, 2003).

Stake (1995) divides case studies into three types based on their analytical goal: intrinsic, instrumental, and collective. According to Stake (1995), researchers who want to investigate a unique scenario would do an intrinsic case study. In this scenario, Stake assures that the focus is on the case itself, and the transferability of the study results is limited. Stake (1995) suggests using an instrumental case study when the purpose of the inquirer is to get additional insights into a specific occurrence. Stake (1995) describes specific steps to obtain a better knowledge of the case in this instance: "a research question, a puzzlement, a need for general understanding, and feeling that we may get insight into the question by studying a particular case" (p. 3). Stake (1995) describes collective-case studies, also known as multiple-case studies, as case studies that investigate a problem of interest in order to obtain a deeper knowledge of it. Cases, such as programs or activities, can be picked from a single or numerous research sites in this situation.

4. General guidelines/rules

In his book Qualitative Research and Evaluation Methods, Patton (2015) provides a set of eight clear and thorough rules for constructing case studies. Patton highlights the significance of thoroughly analyzing each case before moving on to a cross-case study. Each case is unique, according to Patton (2015), and it is the researcher's obligation to achieve justice by noting the distinctive aspects of each

case independently. Patton then confirms that the inquirer should seek analysis for particular examples that constitute the smaller units of analysis. “No matter what you are studying, always collect data on the lowest level unit of analysis possible” (Patton, 2015, p. 536). Patton also encourages case study scholars to combine data from many sources while doing case studies. Patton's next piece of advice is to report the case in a descriptive narrative with a beginning, middle, and end. Furthermore, the reader should be kept in mind by delivering a clear core story of the case. The investigator should take the reader to the point of investigation by offering a thorough and exhaustive narrative of the case or instances. Patton then proposes asking a peer reviewer for feedback to double-check the reliability and coherence.

5. Procedures for conducting a case study

Merriam and Tisdell (2015), Stake (1995), and Yin (2009, 2014) are all excellent resources for explaining different case study approaches (Creswell & Poth, 2018). Creswell and Poth (2018) offer four stages for conducting a case study based on Stake (1995) and Yin (2014). First, the researcher must decide whether the case study method is appropriate for investigating the research issue. This process should include finding cases with limits and determining whether to examine cases for in-depth comprehension or perform a case comparison. Second, the inquirer must determine the purpose of the study and carefully select the subject or cases. The type of case study, whether a single or multiple-case study, and the type of sampling, which is usually an intentional sample, should be chosen during this step. Third, the researcher must devise a technique for gathering data from various sources. Data can be gathered through interviews, direct observations, participant observation, tangible artifacts, and documentation. “Yin (2014) recommends six types of information to collect: documents, archival records, interviews, direct observations, participant observation, and physical artifacts” (Creswell & Poth, 2018, p. 100). Fourth, while focused on a specific instance issue, the researcher must build a comprehensive approach for assessing the obtained data. Beginning researchers, according to Baxter and Jack (2008), should use either Yin's or Stake's data analysis approaches.

Yin developed five methodologies, including pattern matching, relating data to propositions, explanation building, time-series analysis, logic models, and cross-case synthesis. Stake, on the other hand, essentially summarizes two analysis methods: categorical aggregation and direct interpretation. The data collected and processed should then be thoroughly described. The researcher may focus on a specific issue(s) that will lead to a deeper grasp of the case's complexity rather than generalizing the findings with such detailed descriptions. Finally, the researcher will write a report outlining the case study and the lessons learned. A reflective report must be described and "organized with readers in mind" (Stake, 1995, p. 122). One or more of Yin's six-case reporting procedures may be advantageous for beginning researchers. Linear, comparative, chronological, theory-building, suspense, and un-sequenced ways are among Yin's reporting strategies (Yin, 2003). Stake (1995) states that “the report is just one person’s encounter with a complex case” (p. 123). Merriam agrees with Stake, who regards the report as a product that conveys the researcher's point of view. “The final product of this type of study is yet another interpretation by the researcher of others’ views filtered through his or her own” (Merriam, 1998, p. 22).

Merriam (1998) blends the Yin and Stake methods, with the primary emphasis being placed on the

research of published works. Merriam (1998) recommends that novice researchers perform a literature review as a means of gaining assistance in conceptualizing their work and developing a theoretical framework. She gives very detailed advice on how to do a literature review.

Patton (2015) breaks the methodology of doing case studies down into three distinct components. Collecting the data for the row cases is the first step in the process. The second step, which is completely voluntary, is putting together a case file. Patton (2015) recommends that the researcher provide a file with the row data sorted and classified in a certain way. The very last thing you need to do is compose the very last story for the case study. Patton asserts that the narrative will be easy to read and rich with information, supplying the reader with exhaustive details about each component of the analysis and facilitating the reader's comprehension of the situation. He may relate it in a fashion that is chronological or one that is conceptual.

6. Examples of case-study research

In their 2001 study, *Jermaine: A Critical Case Study of a Talented Black Youngster Living in Rural Poverty*, Hébert and Beardsley (2001) used a qualitative case study approach with aspects of critical ethnography research. The study's overarching goal was to examine the impact of the rural setting on the academic success of a bright black youngster who was raised in an impoverished rural community. Taylor's (2006) comparative case study, aiming to investigate learning in an informal community setting, is another example. In *Making Meaning of Local Nonformal Education: A Practitioner's Perspective*, Taylor (2006) compared the similarities between the planning and instruction of educational activities at state parks and home improvement centers. A third example is Collins and Hansen's *Great by Choice: Uncertainty, Chaos, and Luck—why some thrive despite them all*. Collins and Hansen (2011) conducted a widely-cited case study to determine what set apart high-performing organizations from their average-performing counterparts over a period of 15 years.

7. Procedures for conducting a case study

This paper is a humble attempt to help inexperienced researchers overcome the challenges of conducting case studies by providing fundamental guidelines that case-study pioneers like Yin, Stake, and Merriam have advised and provided. This article is a part of a larger collection of articles that collectively make up the Case Study Rookie's Guide. The process of establishing the case is likely to be the first obstacle that novice researchers encounter. Choosing the appropriate unit of analysis is another obstacle that must be overcome by rookie and experienced researchers alike (Baxter & Jack 2008). Researchers should ask themselves a number of questions about what they want to analyze, according to Baxter and Jack (2008). These questions include: Is the case broad or narrow in scope? How many cases are to be studied? Is it a single-case or multiple-case study? as well as how many cases are to be studied? In order to overcome such a challenge, researchers should ask themselves these questions. Finding the unit of analysis, if such a thing even exists, will be easier for researchers to do if they have the answers to these questions. When writing the report, the results must be presented to the reader in a way that is straightforward in order for them to be relevant to the purpose of the report (Stake, 1995). When describing the findings, the researcher who is also writing the report has a responsibility to keep the readers in mind.

Finally, novice researchers should adhere to the general methods for conducting qualitative research while paying close attention to case study specific criteria. Here are some tips to help rookie researchers do good case study research based on the historical overview and pioneers' viewpoints and techniques presented in the article.

(a) Create a clear protocol for the research process that addresses the uniqueness of each case.
(b) Carefully define the case of study.
(c) Based on the research objectives, choose the type of case study.
(d) Determine the scope of each case's boundaries to ensure the relevancy of acquired data and a better understanding of the case's context.
(e) In the case of a multiple-case study, researchers must properly investigate each case before going on to the next instance.
(f) Examine existing literature to identify research gaps and refine research questions.
(g) To avoid implicit bias, engage in reflexivity by regularly reflecting on how your background, experiences, and perspectives may influence your perception of the data.
(h) To avoid data misinterpretation, provide a straightforward description of the findings apart from views.

8. References

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report, 13*(4), 544-559. https://doi.org/10.46743/2160-3715/2008.1573

Collins, J., & Hansen, M. (2011). *Great by choice: Uncertainty, chaos, and luck - why some thrive despite them all.* HarperCollins.

Creswell, J. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). SAGE Publications, Inc.

Creswell, J., & Poth, C. (2018). *Five qualitative approaches to inquiry. In qualitative inquiry & research design: Choosing among five approaches* (4th ed., pp. 65-110). SAGE Publications.

Glaser, G., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Aldine Pub. Co.

Hébert, T., & Beardsley, T. (2001). Jermaine: A critical case study of a gifted black child living in rural poverty. *The Gifted Child Quarterly, 45*(2), 85–103. https://doi.org/10.1177/001698620104500203

Merriam, S. (1998). *Qualitative research and case study applications in education*. Jossey-Bass.

Merriam, S. (2009). *Qualitative research: A guide to design and implementation* (2nd ed.). Jossey-Bass.

Merriam, S., & Tisdell, E. (2015). *Qualitative research: A guide to design and implementation*. Wiley.

Patton, M. (2015). *Qualitative research and evaluation methods* (4th ed.). SAGE Publications, Inc.

Stake, R. (1995). *The art of case study research.* SAGE Publications.

Stake, R. (2000). Case studies. In N. K. Denzin & Y. S. Lincoln (eds), *Handbook of qualitative research* (2nd ed. Pp. 435-454). Sage.

Stewart, A. (2014). Case study. In Jane Mills & Melanie Birks (Eds.), *Qualitative methodology: A practical guide* (pp. 145-159). Sage.

Taylor, E. (2006). Making meaning of local nonformal education: Practitioner's perspective. Adult *Education Quarterly, 56*(4), 291-307.

Yin, R. (2002). *Case study research: Design and methods.* SAGE Publications.

Yin, R. (2003). *Case study research: Design and methods* (3rd ed.). Sage.

Yin, R. (2009). *Case study research: Design and methods*. Sage.

Yin, R. (2014). *Case study research: Design and methods* (applied social research methods series, 5th edition). Sage.

A Twitter Sentiment Analysis Dashboard for Covid-19: The Case of Kansas

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Abstract

This study focuses on analyzing people's tweets in the state of Kansas during the Covid-19 pandemic. Data was collected using the Twitter API from January to September of 2020. We developed a custom back-end algorithm to collect and accumulate daily tweets over time. We then cleaned the tweets and performed sentiment analysis to identify positive, negative, and neutral tweets. Finally, we developed a front-end algorithm to generate a custom dashboard containing several interactive visualizations and made the dashboard available online. The study describes the background, methodology and results.

Keywords: Covid-19, Dashboard, Python, Sentiment Analysis.

1. Introduction

Prior to Covid-19, two variants of coronaviruses caused severe illnesses. The first was severe acute respiratory syndrome (SARS) in 2002, followed by the Middle East respiratory syndrome in 2012 (Jolly, 2016; Smith, 2006). Neither was as deadly as the coronavirus that started in December 2019 in a seafood market in Wuhan, China. This virus was later labeled by the World Health Organization as Covid-19, which stands for Coronavirus Disease 2019 (Lai et al., 2020). Once it started, Covid-19 spread exponentially. At the end of March 2020, the number of Covid -19 cases in the United States ranged from a few dozen to 200,000 cases. The U.S. president at that time, Donald Trump, declared Covid a national emergency. More than one million cases had been reported in more than 150 countries, resulting in 50,000 deaths. On March 11,2020 the World Health Organization declared the novel Covid-19 outbreak a global pandemic (Cucinotta et al., 2020).

The outbreak of Covid-19 had a significant impact on both global and local economies. To prevent the spread of Covid-19, governments enforced border shutdowns and travel restrictions. This has led to the risk of an economic crisis in many countries (Nicola et al., 2020). When the pandemic spread rapidly, there was a mass panic that caused people to purchase large quantities of medical and essential goods. That led to shortages and supply chain challenges. The pandemic has also impacted work and education. According to UNESCO, over 1.5 billion learners in 195 countries were not able to attend school due to the shutdown of schools and colleges. Some countries were able to provide online learning, but several others did not have the resources or technology required (Tadesse et al., 2020). Many employees were unable to work remotely and lost their jobs due to Covid-19, which resulted in more hardship.

During the pandemic, Twitter became a popular means for people to share information, tips, opinions, and feelings regarding various Covid-19 issues in real time. Twitter also let users find information on a particular topic by searching on a hashtag or reading about trending hashtags.

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Government and non-government organizations have used Twitter to collect information about a crisis and develop a relief plan for the people affected (Gao et al., 2011). Since Twitter is easy to use, it has a wide range of audience and can be of great use during emergencies (Simon et al., 2015; Carley et al., 2016; Martinez-Rojas et al., 2018). However, it could also pose a challenge because the information shared on Twitter may be unreliable, incorrect, and users may be misled if they do not check the credibility of the source (Castillo et al., 2011).

A popular trend during the pandemic was the use of dashboards by various organizations (education, health, government, etc.) to track infection rates, death rates, and vaccination rates. A popular one was the John Hopkins dashboard that tracked Covid-19 cases around the world in real time. However, the effectiveness of such global dashboards in the local communities was limited. Moreover, there were no dashboards at the time to track people's sentiments and opinions about Covid-19. While people found tracking information about death rates helpful, many wanted to use Twitter just to complain, ask questions about testing, symptoms, precautions, where to purchase items, their children's schools, etc.

In this study, we addressed a critical gap in the Covid-19 literature by creating a specialized dashboard for Kansas, designed to aggregate, analyze, and display Twitter data. This innovative dashboard, developed with a custom approach, allows for the real-time collection and sentiment analysis of data. This tool is instrumental in offering real-time insights into public opinions regarding governmental policies and community issues, particularly in the context of the Covid-19 pandemic. The primary goal of this sentiment analysis tool is to empower responsive governance, enabling policymakers to gain a deeper understanding of public sentiment. This understanding is crucial for making informed decisions that resonate with the public's concerns and needs. Additionally, it plays a significant role in identifying the aspects of policies or issues that are most pressing to the public, thereby addressing the most urgent areas of concern in pandemic management and policy formulation.

Beyond individual policies, the broader impacts of our study include its role in crisis management and public engagement. During crises, our tool's rapid sentiment analysis capabilities are crucial for governments to develop effective communication and intervention strategies. Moreover, the tool serves as a platform for gauging and enhancing public engagement with policy matters. This engagement not only helps in understanding public opinion but also promotes a more democratic and participatory approach to governance. Our study thus highlights the transformative potential of sentiment analysis in creating responsive, effective, and inclusive public policies, bridging the gap between government actions and public needs. In the following sections, we describe the methods, results, and conclusions of the study.

2. Literature Review

Many researchers used Twitter data to analyze various Covid-19 issues. Ahmed et al. (2020) applied social network analysis to study the 5G conspiracy theory that was spread over Twitter using the hashtag #5GCoronavirus. Lyu et al. (2021) used topic modeling and sentiment analysis to analyze the discussions on Twitter related to the Covid-19 vaccine. Al-Rawi et al. (2020) studied the use of emojis related to Covid-19 by different genders (male, female, nonbinary). Alhajji et al. (2020) analyzed tweets from Saudi Arabia to understand the reaction of Saudi's towards the methods for preventing Covid-19. They used the Naive Bayes algorithm to perform sentiment analysis.

Depoux et al. (2020) addressed the need to combat the pandemic of social media panic. It emphasized the importance of using social media wisely. They also mentioned how it can help people cope with difficulties of isolation. The importance of disseminating information through various social media sites was explained by Merchant & Lurie (2020). They emphasized the importance of exchanging accurate and reliable information during crises such as the Covid-19 outbreak. They encouraged the use of social media to provide information regarding the virus, when to get tested, what to do with the results, and where to receive medical care. Therefore, posting wrong and misleading information can potentially be life threatening.

Talwar et al. (2019) studied the dark side of social media use and fake news sharing. Their model was based on ten hypotheses to test whether online trust, self-disclosure, and other factors were related to the sharing of fake news and authenticating the news before sharing it. Sharma et al. (2020) identified tweets that spread misinformation and studied the narratives included in the tweets as well as the engagements of those tweets. They created a dashboard that showed a list of these misleading tweets along with other topics about Covid-19. Fan & Gordon (2014) mentioned that social media analytics can help collect, monitor, and visualize data to discover patterns in the data. They stated that social media analytics included a three-stage process: capture, understand and present. The process involved collecting necessary data, cleaning it, and discovering its meaning through data mining and visualization tools.

3. Methodology

Sentiment Analysis (SA) is a Natural Language Processing (NLP) technique used to identify positive and negative sentiments in any text. Sentiment Analysis helped companies with their marketing of new products, and assisted organizations in making better decisions regarding policies (Zhou et al., 2013). It has also been used for stock-market prediction, box-office prediction, political voting forecasts and public opinion monitoring (Li et al., 2018). Twitter Sentiment Analysis (TSA) is when Twitter data is used to conduct Sentiment Analysis. The techniques used in TSA are Machine Learning approach (ML), Lexicon-based approach (LB) and the Hybrid approach.

To develop our Twitter Sentiment Analysis dashboard for Kansas, we used the Lexicon-based approach to calculate the positive, negative, and neutral sentiments of the tweets. We acknowledge that Lexicon-based approaches have limitations in deep context analysis compared to advanced machine learning techniques. However, the scope and scale of this study provided a balance between accuracy and computational efficiency. The sentiment scoring algorithm used in this study does more than merely sum up positive and negative words. It considers Part-of-speech (POS) Tagging, which aids in understanding the grammatical role of words, providing insights into how words in a sentence influence each other's sentiment and linguistic Rules, following specific rules that define how different parts of a sentence interact, offering a more general understanding of sentiment than simple word count. Different algorithms were used to design the back end and front-end of the dashboard. While there are different programming language options that we could have used, we chose Python because it supports multiple programming paradigms and has a comprehensive collection of efficient and powerful libraries to conduct sentiment analysis. Figure 1 depicts a flowchart of the three phases of the dashboard back-end.

3.1. Data Collection

At the time of the study, there were various methods available to collect Twitter data, some for purchase from data providers and others for free using an Application Programming Interface (API). We used GetOldTweets3, which was the free Python library that allowed us to scrape less than 1% of the data from Twitter. We were able to use search parameters such as start/end dates, usernames, text search, hashtags, and location as well. We used a PowerShell script that contains the necessary Python code to import the GetOldTweets3 package to collect the tweets containing the keyword Covid-19 (or any variants of the word) from January to September 2020. The program ran every morning at 12.15 am to collect tweets from every county seat in Kansas in the last 24 hours using the Windows scheduling technology. This program is flexible and has several advantages. It was automatically stopped and resumed. There were no restrictions on obtaining a large number of tweets. Since many tweets are collected at a single time, there will be some timeout problems that can be handled automatically by this program. It also converts the date and time of the tweets to datetime objects along with the conversion to US Central time. This program collects only tweets from the previous day, so the date and time in the program are set to the current date and time. The main city in each county is usually the county seat. We used an online reference to find all the county seats in Kansas, with a total of 104. We had a total of about 37,000 tweets.

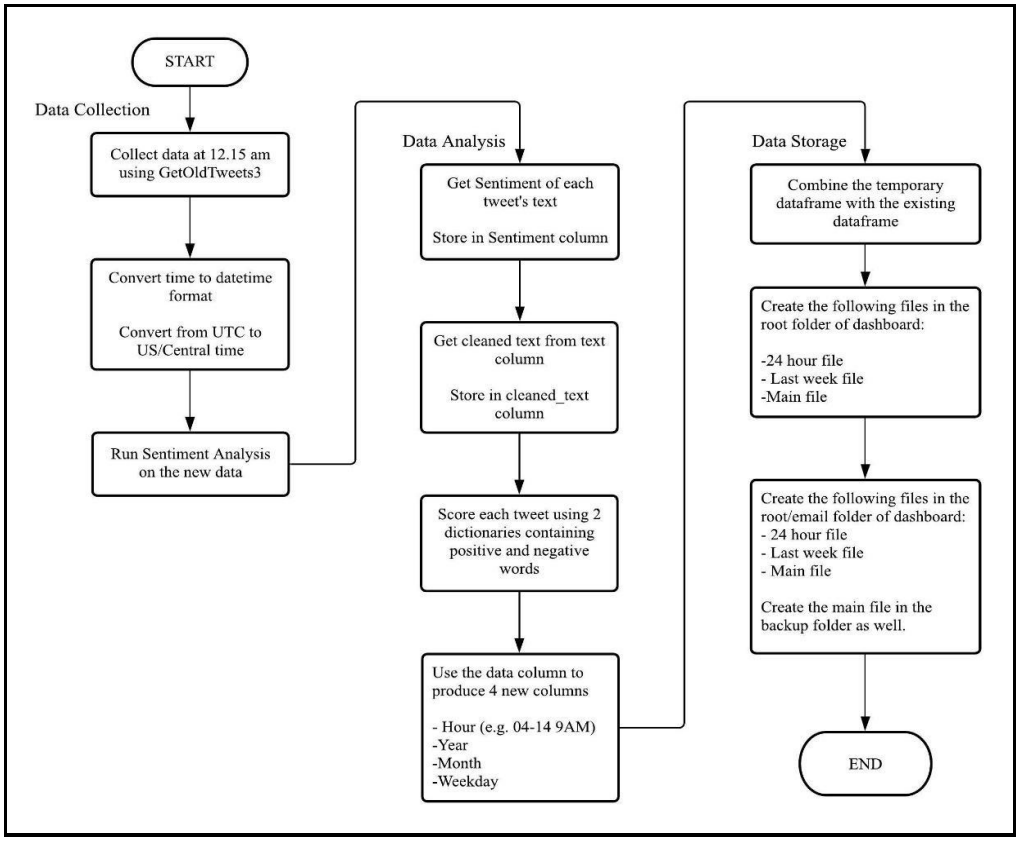

Figure 1. Flowchart of the Dashboard Back-End

3.2. Data Pre-processing

The Tweet's content was then cleaned using the Natural Language Toolkit (NLTK). NLTK consists of programs for natural language processing (NLP) written in Python. It can perform various NLP tasks, such as tokenization, stemming, POS tagging, and lemmatization to name a few. NLTK contains a list of stop words in 16 different languages. It removes stop words such as punctuation, hyperlinks, and special characters from the collected tweets. We then saved the calculated sentiments and cleaned the Tweet text in different columns. After data cleaning was performed, scoring was done using the TextBlob library to classify the sentiment of the tweet as positive (+1), negative (-1), or neutral (0). After this process, the date and time in a single column are divided into four columns where the first column is for an hour (e.g., 9 pm), the second for a year (e.g., 2020), the third for a month (e.g., January) and fourth for the day of the week (e.g., Monday). This whole process is done recurringly everyday morning at 12:15 am.

3.3. Data Storage

The collected and pre-processed data were then stored in a different file which is the master file. The daily cleaned data were appended to the master dataset in Comma Separated Values (CSV) format. This dataset contained duplicates. Every tweet has its own unique Tweet ID provided by Twitter. Therefore, duplicate tweets were removed using their Tweet ID. Then, the dataset was stored in three different files: "24-hour file", "Last week file" and "Main file". The 24-hour file contains data from the previous day. The Last week file contains data from the previous week, and the Main file contains the cumulative up-to-date data.

4. The Dashboard

The front-end of our application is a dashboard that generates different visualizations of Covid-19 tweets and sentiments in Kansas. The front-end consists of two phases: creating the visualizations and developing the dashboard to post online. Figure 2 shows a flowchart of the two phases of the dashboard front-end. It starts with the data files collected, which were cleaned and analyzed in the backend, and generates visualizations that users can interact with by clicking the buttons to analyze the data by day, week, or month. Users can select positive, negative, and neutral sentiments using a dropdown menu. For every visualization, the user can hover over a data point and obtain additional details.

Plotly and WordCloud are the two popular open-source libraries in Python that are used for visualization. Plotly produced high quality graphs that were interactive, such as histograms, density charts, and heatmaps. WordCloud was effective in displaying frequently used hashtags in larger fonts than the other hashtags. The dashboard was created using two open-sources web Framework Python libraries called Dash and Flask. Dash is a web framework used for building web applications. It is the most downloaded framework for building Machine Learning and Data Science web applications. On the other hand, Flask is a lightweight Web Server Gateway Interface (WSGI) framework.

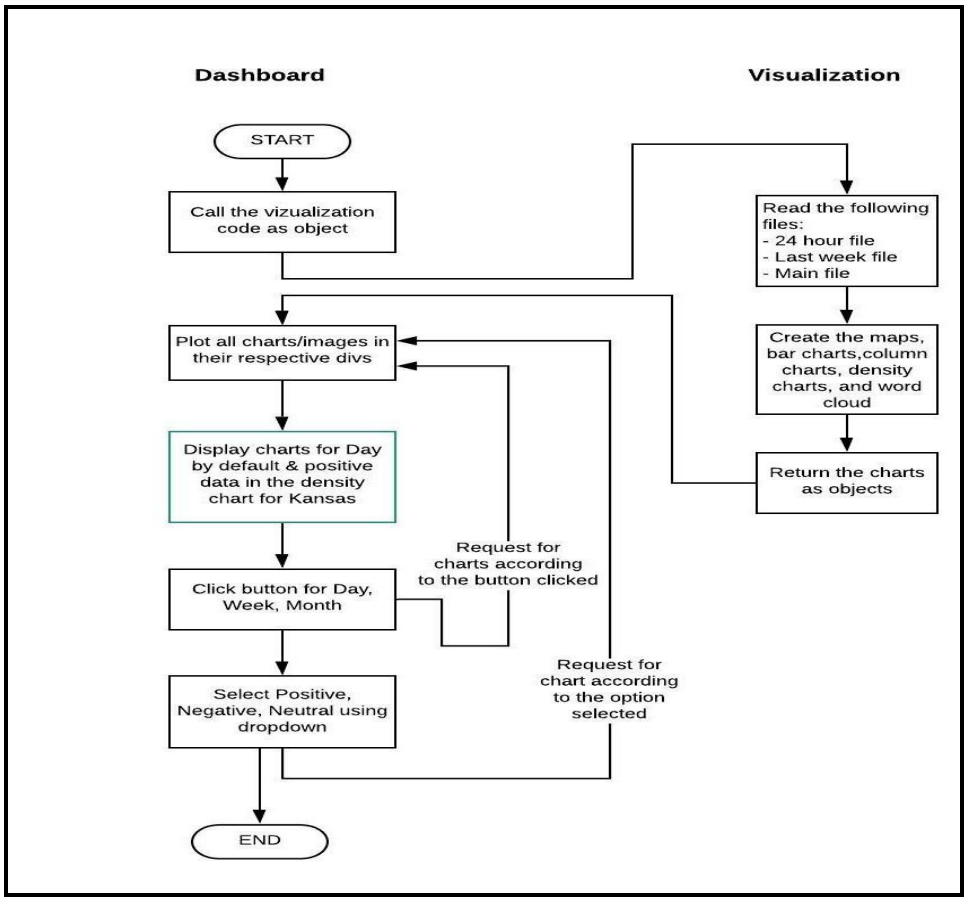

Figure 2. Flowchart of the Dashboard Front-End

5. The Visualizations

We created different visualizations for the display on the dashboard, which at the time of design is found here https://business-analytics.wichita.edu/covid/. Figures 3, 4, and 5 show the snippets of the dashboard visualizations. Unfortunately, they do not illustrate color or the interactive feature of the dashboard. The content of the visualizations is described in the following sections.

Figure 3 shows the following from top down from left to right. First, the user can select the analytics to be displayed by day, week, or month. Next, one can select to look at positive, negative, or neutral tweets. The table shows the counties and their corresponding county seats. Given the selections made, the Choropleth map is generated to show positive (green), negative (red), and neutral (blue) tweets in all the counties of Kansas. The darker the color, the greater the intensity (number) of tweets in that county. The frequency distribution of the intensity level is shown in the top right corner of the map. When one hovers over a county, details are given on the county name, the FIPS code, and number of tweets in that county.

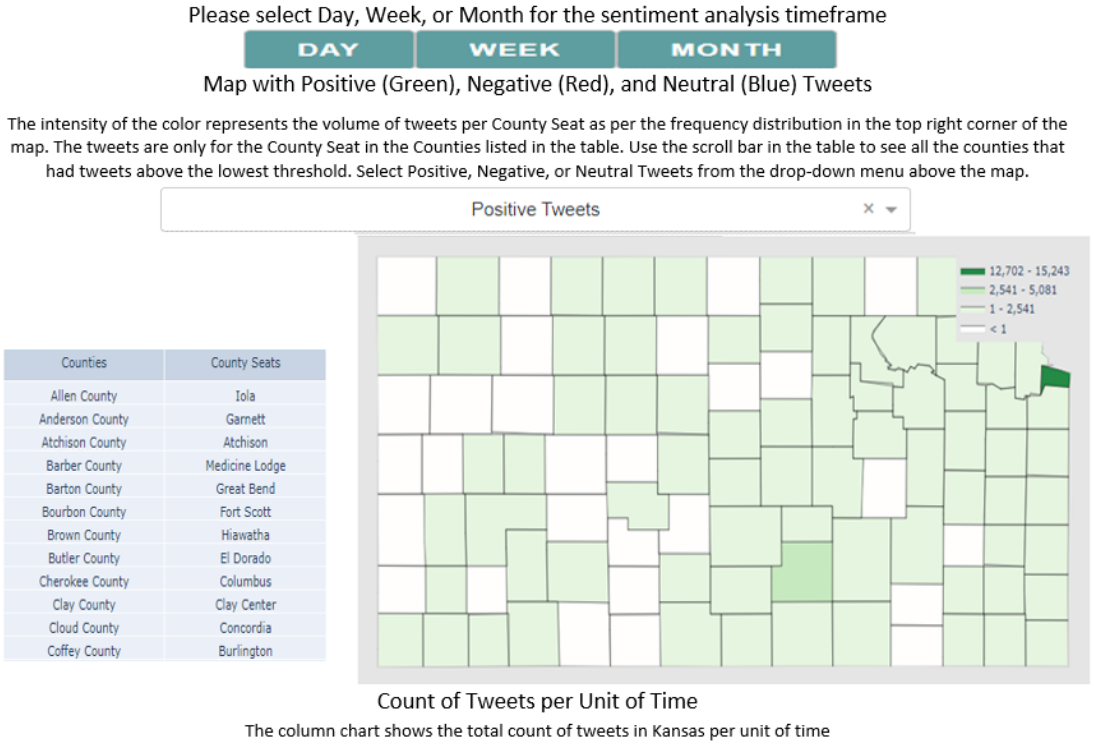

Figure 3. Choropleth Map and List of Kansas County Seats

Next, Figure 4 shows a density chart that shows the volume of all the tweets in Kansas along a timeline and classified as positive, negative, or neutral. The same color scheme was maintained throughout the dashboard. Users can hover their mouse over the dots on the line to obtain more details such as exact date and number of tweets.

Finally, Figure 5 shows three bar charts. The top row chart displays the number of the 15 most popular words in the tweets. The top of the list was Covid followed by words such as people, pandemic, Kansas and health. The second row consists of two charts, one for the 15 most popular positive words, and the other for the 15 most popular negative words in the tweets. The positive words included like, support, thank, protect and relief. Negative words included virus, crisis, risk, symptoms, and emergency.

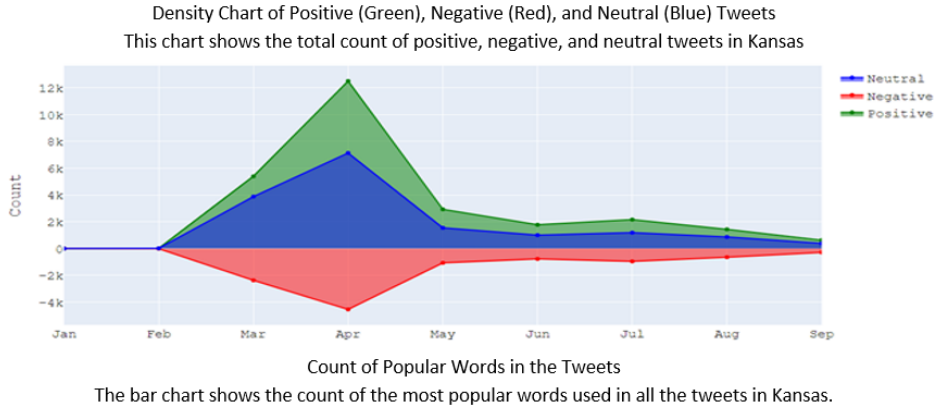

Figure 4. Density Chart of Number of Tweets Over Time

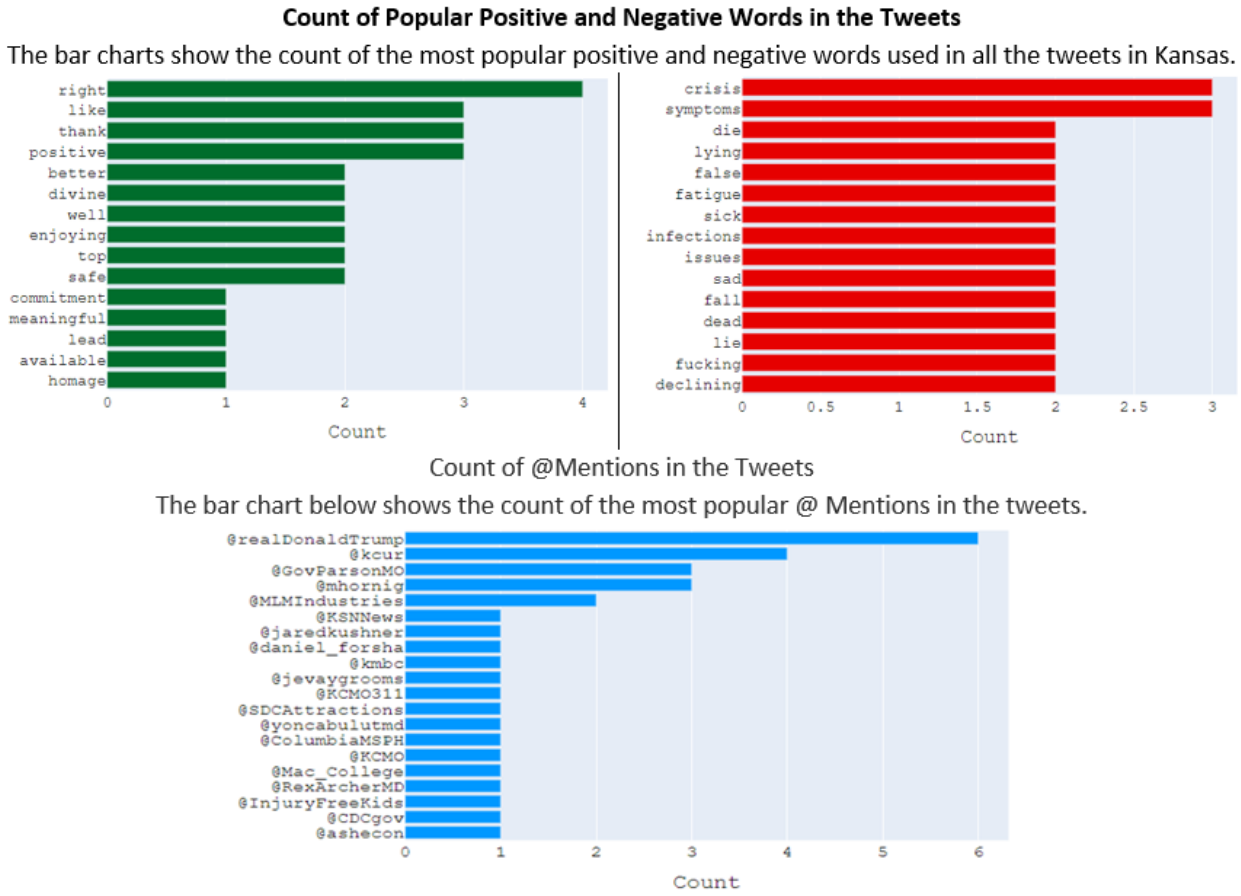

Figure 5. Bar Charts of Popular Words and @ Mentions

There were other charts on the dashboard that were not displayed in figures 3-5. These include top @ mentions in the tweets and the Word Cloud. The top mention was @realdonaldtrump @GoveLauraKelly, which were the Twitter handles for president Trump and Kansas governor Kelly at the time of the study. Another chart was the Word Cloud that displayed the most frequent hashtags mentioned in the tweets. The most popular hashtags included covid19, ksleg, and stayhome.

6. Conclusions and Future Research

In this study, we focused on analyzing the tweets that were posted by people in Kansas during the Covid-19 pandemic. We collected tweets from every county seat in Kansas using a custom model that we developed in Python to accumulate the tweets for free. After pre-processing the tweets, we then analyzed the sentiments of the tweets and classified them as positive, negative, and neutral. We then created several visualizations and displayed them on a dashboard that was updated in real time. The dashboard was posted online and allowed the end user to check the people's sentiments by day, week, or month. The dashboard allowed Kansans to track their sentiments about Covid. Other dashboards at the time only tracked Covid cases and deaths. The limitations of this study included focusing on one state and only on the freely available tweets, which accounted for less than 1% of all tweets. At the time, this was what Twitter had allowed. Recently, Twitter has made it even more difficult to obtain free tweets. One needs to pay to purchase the Twitter data. Future research can focus on expanding the

study to other states and generalizing the use of the methodology presented in this paper to other emergency topics, such as earthquakes and tornados. Additionally, it is suggested that future investigations could explore more advanced context analysis techniques, employing Deep Learning Models like Bidirectional Encoder Representations from Transformers (BERT) or Generative Pretrained Transformers (GPT). These models are better equipped for understanding context and the complexities of language, potentially offering more insightful analyses in these areas.

7. References

Ahmed, W., Vidal-Alaball, J., Downing, J., & López Seguí, F. (2020). COVID-19 and the 5G Conspiracy Theory: Social Network Analysis of Twitter Data. *In Journal of Medical Internet Research* (Vol. 22, Issue 5, p. e19458).

Alhajji, M., Al Khalifah, A., Aljubran, M., & Alkhalifah, M. (2020). Sentiment Analysis of Tweets in Saudi Arabia Regarding Governmental Preventive Measures to Contain COVID-19.

Al-Rawi, A., Siddiqi, M., Morgan, R., Vandan, N., Smith, J., & Wenham, C. (2020). COVID-19 and the Gendered Use of Emojis on Twitter: Infodemiology Study. In *Journal of Medical Internet Research* (Vol. 22, Issue 11, p. e21646).

Carley, K. M., Malik, M., Landwehr, P. M., Pfeffer, J., & Kowalchuck, M. (2016). Crowd sourcing disaster management: The complex nature of Twitter usage in Padang Indonesia. In *Safety Science* (Vol. 90, pp. 48–61).

Castillo, C., Mendoza, M., & Poblete, B. (2011). Information credibility on twitter. In *Proceedings of the 20th international conference on World wide web*.

Cucinotta, D., & Vanelli, M. (2020). WHO Declares COVID-19 a Pandemic [JB]. Acta Bio Medica Atenei Parmensis, 91(1), 157–160.]

Depoux, A., Martin, S., Karafillakis, E., Preet, R., Wilder-Smith, A., & Larson, H. (2020). The pandemic of social media panic travels faster than the COVID-19 outbreak. In *Journal of Travel Medicine* (Vol. 27, Issue 3)

Fan, W., & Gordon, M. D. (2014). The power of social media analytics. In *Communications of the ACM* (Vol. 57, Issue 6, pp. 74–81).

Gao, H., Barbier, G., & Goolsby, R. (2011). Harnessing the Crowdsourcing Power of Social Media for Disaster Relief. In *IEEE Intelligent Systems* (Vol. 26, Issue 3, pp. 10–14).

Jolly, G. (2016). Middle East Respiratory Syndrome Coronavirus (MERS-CoV). In *TEXILA INTERNATIONAL JOURNAL OF PUBLIC HEALTH* (Vol. 4, Issue 4, pp. 351–376).

Lai, C.-C., Shih, T.-P., Ko, W.-C., Tang, H.-J., & Hsueh, P.-R. (2020). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. In *International Journal of Antimicrobial Agents* (Vol. 55, Issue 3, p. 105924).

Li, Z., Fan, Y., Jiang, B., Lei, T., & Liu, W. (2018). A survey on sentiment analysis and opinion mining for social multimedia. In *Multimedia Tools and Applications* (Vol. 78, Issue 6, pp. 6939–6967).

Lyu, J. C., Han, E. L., & Luli, G. K. (2021). COVID-19 Vaccine–Related Discussion on Twitter: Topic Modeling and Sentiment Analysis. *In Journal of Medical Internet Research* (Vol. 23, Issue 6, p. e24435).

Martínez-Rojas, M., Pardo-Ferreira, M. del C., & Rubio-Romero, J. C. (2018). Twitter as a tool for the management and analysis of emergency situations: A systematic literature review. In *International Journal of Information Management* (Vol. 43, pp. 196–208).

Merchant, R. M., & Lurie, N. (2020). Social Media and Emergency Preparedness in Response to Novel Coronavirus. In *JAMA* (Vol. 323, Issue 20, p. 2011).

Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, M., & Agha, R. (2020). The socio-economic implications of the coronavirus pandemic (COVID-19): A review. In *International Journal of Surgery* (Vol. 78, pp. 185–193)

Sharma, K., Seo, S., Meng, C., Rambhatla, S., & Liu, Y. (2020). COVID-19 on Social Media: Analyzing Misinformation in Twitter Conversations (Version 4).

Simon, T., Goldberg, A., & Adini, B. (2015). Socializing in emergencies—A review of the use of social media in emergency situations. In *International Journal of Information Management* (Vol. 35, Issue 5, pp. 609–619).

Smith, R. D. (2006). Responding to global infectious disease outbreaks: Lessons from SARS on the role of risk perception, communication, and management. In Social Science; Medicine (Vol. 63, Issue 12, pp. 3113–3123).

Tadesse, S., & Muluye, W. (2020). The Impact of COVID-19 Pandemic on Education System in Developing Countries: A Review. In *Open Journal of Social Sciences* (Vol. 08, Issue 10, pp. 159–170).

Talwar, S., Dhir, A., Kaur, P., Zafar, N., & Alrasheedy, M. (2019). Why do people share fake news? Associations between the dark side of social media use and fake news sharing behavior. In *Journal of Retailing and Consumer Services* (Vol. 51, pp. 72–82).

Zhou, X., Tao, X., Yong, J., & Yang, Z. (2013). Sentiment analysis on tweets for social events. In Proceedings of the 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design (CSCWD).

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