JOURNAL OF MANAGEMENT AND ENGINEERING INTEGRATION

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Evaluating the Impact of Student Constructed Four-Bar Mechanisms on Achieving Learning Objectives in An Industrial Mechanisms Course

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Abstract

A comparison of achieving learning outcomes for kinematic analysis is given between two semesters of an Industrial Mechanisms course. The variable introduced is an active learning based teaching method in the form of a student constructed four-bar mechanism that is used in all kinematic analysis related discussions and assignments. The measure of comparison is instructor observations, student coursework assessments, and student feedback. The use of active learning teaching methods is shown to have a statistically significant positive impact on learning performance.

1. Introduction

Mechanical and Industrial Engineering Technology majoring students at the University of Dayton have as part of their undergraduate required curriculum an industrial mechanisms course. This course introduces students to a broad set of industrial mechanism topics including application, design, and analysis methods. The four-bar mechanism (a.k.a. four-bar linkage), often described as "the most common and ubiquitous device used in machinery", naturally occupies a significant focus in the course (Norton, 2001). As such, several course learning objectives focus on the study of four-bar mechanisms:

1. Graphically and analytically determine the displacement of any point on a mechanism.
2. Construct the path of motion of any point in the mechanism.
3. Design a linkage to achieve the desired displacement.
4. Graphically and analytically determine the velocity of any point on a mechanism.
5. Graphically and analytically determine the acceleration of any point on a mechanism.
6. Construct motion diagrams for any point on a mechanism.

These learning objectives, taken as a whole, aim toward teaching the student how to conduct a complete kinematic analysis on any classification of four-bar mechanism. Graphical approaches (hand drawings and CAD renderings) and analytical approaches (hand calculations and spreadsheet tabulations) are both utilized in the delivery of the kinematic analysis materials.

The focus of this paper is a comparative analysis of student achievement toward the six learning objectives specified above using teaching methods with and without active learning components in the form of a student constructed four-bar mechanism. Quantitative metrics of comparison include homework and test performance. Qualitative comparisons based on instructor observations and student feedback is also incorporated into the assessment.

1.1. Four-Bar Mechanism

A schematic representation of a crank-rocker style four-bar mechanism is shown in Figure 1. Typical information known about such a four-bar mechanism would include the length of each of the links (#1 frame L1, #2 input/crank L2, #3 coupler L3, and #4 output/follower L4) as well as the angle, θ2, angular velocity, ω2, and angular acceleration, α2, of the input link at a given moment. With this information, a complete kinematic analysis of the four-bar mechanism can be computed. Equations 1-8 present the closed form equations that describe the kinematics of the four links in a four-bar mechanism configured in the shown configuration. The reader is directed to several number of reference materials related to kinematic analysis, such as "Machines & Mechanism: Applied Kinematic Analysis" by David Myszka (Myszka, 2012) for a complete description of four-bar kinematic analysis.

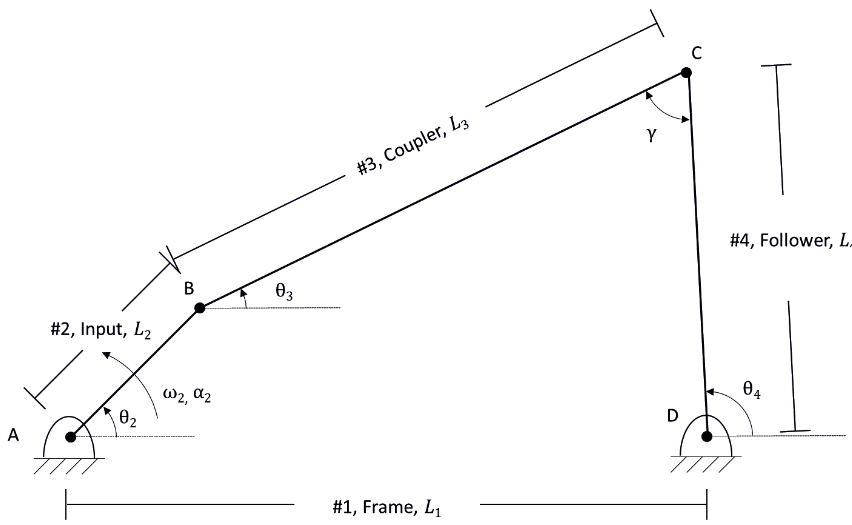

Figure 1. Schematic representation of crank-rocker four-bar mechanism

$$\bar{B}D = \sqrt{(L_1)^2 + (L_2)^2 - 2 \cdot L_1 \cdot L_2 \cdot \cos\theta_2} \tag{1}$$

$$\gamma = \cos^{-1}\left(\frac{(L_3)^2 + (L_4)^2 - \bar{B}D^2}{2 \cdot L_3 \cdot L_4}\right) \tag{2}$$

$$\theta_3 = 2 \cdot \tan^{-1}\left(\frac{-L_2\sin\theta_2 + L_4\sin\gamma}{L_1 + L_3 - L_2\cos\theta_2 - L_4\cos\gamma}\right) \tag{3}$$

$$\theta_4 = 2 \cdot \tan^{-1}\left(\frac{L_2\sin\theta_2 - L_3\sin\gamma}{L_2\cos\theta_2 + L_4 - L_1 - L_3\cos\gamma}\right) \tag{4}$$

$$\omega_3 =- \omega_2 \cdot \left[\frac{L_2\sin(\theta_4 - \theta_2)}{L_3\sin\gamma}\right] \tag{5}$$

$$\omega_4 =- \omega_2 \cdot \left[\frac{L_2\sin(\theta_3 - \theta_2)}{L_4\sin\gamma}\right] \tag{6}$$

$$\alpha_3 = \frac{\alpha_2 L_2 \sin(\theta_2 - \theta_4) + (\omega_2)^2 L_2 \cos(\theta_2 - \theta_4) - (\omega_4)^2 L_4 + (\omega_3)^2 L_3 \cos(\theta_4 - \theta_3)}{L_3 \sin(\theta_4 - \theta_3)} \quad (7)$$

$$\alpha_4 = \frac{\alpha_2 L_2 \sin(\theta_2 - \theta_3) + (\omega_2)^2 L_2 \cos(\theta_2 - \theta_3) - (\omega_4)^2 L_4 \cos(\theta_4 - \theta_3) + (\omega_3)^2 L_3}{L_4 \sin(\theta_4 - \theta_3)} \quad (8)$$

1.2. Kinematic Analysis and Methods

Kinematic analysis can be divided into various analysis types such as position, displacement, velocity, and acceleration. These analysis types can be solved using several methods including hand calculations, spreadsheets or tabulated results, and simulation via CAD. The analysis type and solution method are dependent upon the analyst preference and the desired results. Each of the analysis types and solution methods relies to some degree on the application and synthesis of intermediate-level math and dynamic motion principles learned in prior coursework.

1.2.1. Position analysis:

Position analysis determines the spatial location and orientation of various points on the four-bar mechanism. In this analysis type, the four-bar mechanism is positioned at a known location, rA, in the fixed frame of reference, see Figure 2. If the geometry of the four-bar mechanism is known (L1, L2, L3, and L4) and the configuration of interest is specified (θ2), equations 1-4 can be solved giving the angle or the orientation of every other link (θ3 and θ4) in the mechanism. Knowing the geometry and orientation of each link allows a position vector to be expressed from the fixed frame origin to any point on the four-bar mechanism. For example, the position vector to point C, rC, can be expressed as the summation of the position vector from the fixed frame origin to location A, rA, plus the position vector from location A to location B, rAB, plus the position vector from location B to location C, rBC:

$$r_C = r_A + r_{AB} + r_{BC} \quad (9)$$

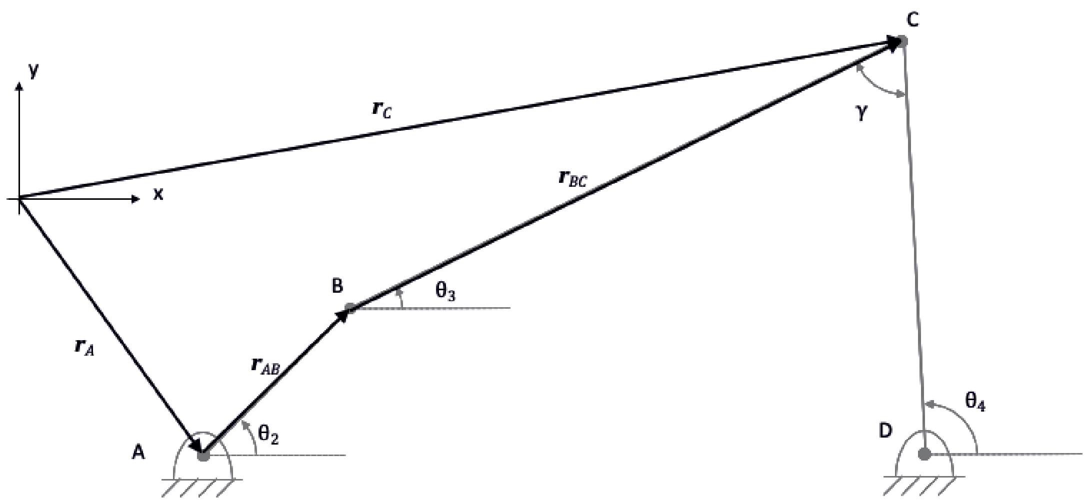

Figure 2. General position analysis of a four-bar mechanism

1.2.2. Displacement analysis:

Displacement analysis determines the linear change in position of any point on a four-bar mechanism and the angular change in orientation for any link in the mechanism between two configurations. A position analysis is first completed for at least two configurations (different input angles, θ2) for the four-bar mechanism. Figure 3 (top & middle) shows the same four-bar mechanism in two configurations. Note that the second configuration labels are denoted by a prime symbol. The linear displacement of a point, e.g. point B, between the two configurations is calculated by taking the difference of the position vectors to point B in each configuration:

$$\Delta r_{BB'} = r_{AB'} - r_{AB} \tag{10}$$

Angular displacement, e.g. of the follower link, is calculated in a similar way:

$$\Delta\theta_4 = \theta_4' - \theta_4 \tag{11}$$

The linear displacement vector for point B and angular displacement of the follower link is shown graphically in Figure 3 (bottom).

1.2.3. Velocity analysis:

Velocity analysis determines the linear velocity of any point on a four-bar mechanism and the angular velocity for any link in the mechanism. Given the angular velocity of the input link, ω_2, the angular velocity of the coupler and follower links can be calculated using equations 5 & 6. The linear velocity for any point on a link in pure rotation (e.g. the input and follower links) is tangential velocity, $\boldsymbol{v}^t$. The magnitude of the tangential velocity of a point, e.g. point B, on a link in pure rotation is calculated by multiplying the angular velocity of the link, ω_2, by the distance between the point of interest and the point about which the link is rotating, L_2:

$$\left\| v_B^t \right\| = \omega_2 \cdot L_2 \tag{12}$$

The direction of the tangential velocity is perpendicular to the line between the point of interest and the point about which the link is rotating in the direction of rotation, see Figure 4. The velocity of a point not on a link in pure rotation utilizes relative velocity analysis techniques; the reader is directed to a kinematic textbook for a full discussion.

1.2.4. Acceleration analysis:

Acceleration analysis determines the total linear acceleration of any point on a four-bar mechanism and the angular acceleration for any link in the mechanism. Given the angular acceleration of the input link, α_2, the angular acceleration of the coupler and follower links can be calculated using equations 7 & 8. The total linear acceleration, $\boldsymbol{a}$, for any point on a link in pure rotation (e.g. the input and follower links) is the vector summation of the tangential, $\boldsymbol{a}^t$, and normal, $\boldsymbol{a}^n$, acceleration components:

$$a = a^t + a^n \tag{13}$$

The magnitudes of the tangential and normal acceleration components of a point, e.g. point B, on a link in pure rotation is calculated using the following:

$$\left\| a_B^t \right\| = \alpha_2 \cdot L_2 \tag{14}$$

$$\left\| a_B^n \right\| = (\omega_2)^2 \cdot L_2 \tag{15}$$

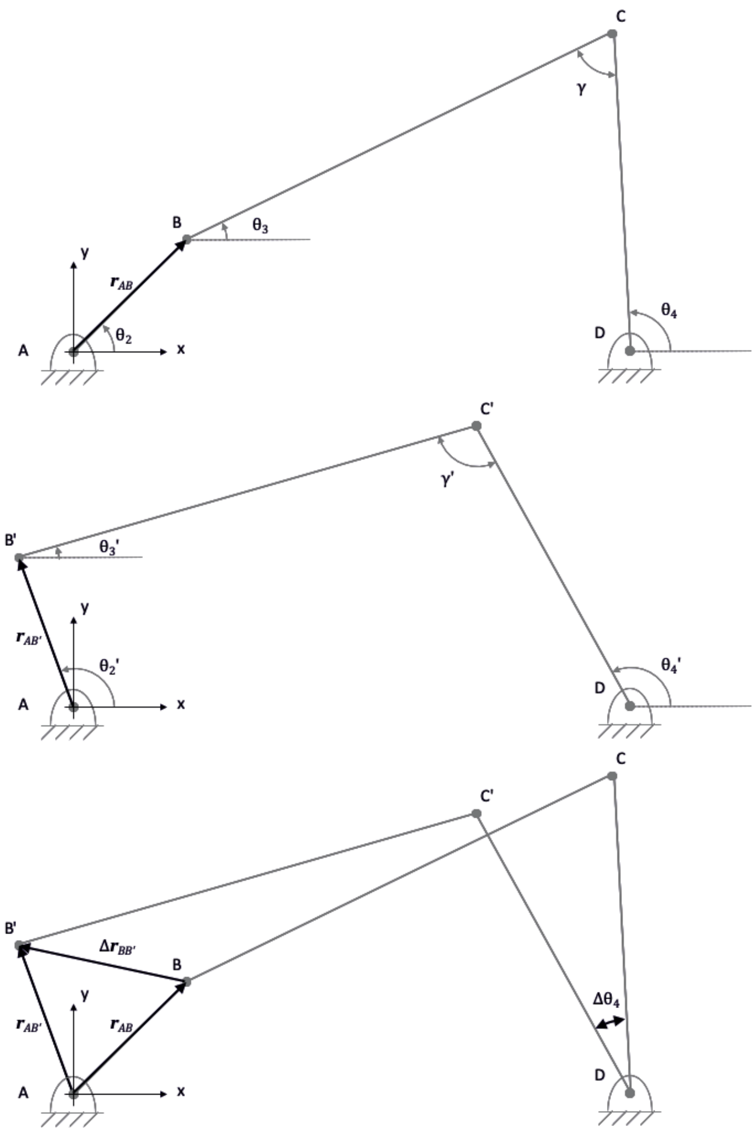

Figure 3. General displacement analysis of a four-bar mechanism; (top) configuration 1, (middle) configuration 2, (bottom) representative linear and angular displacements

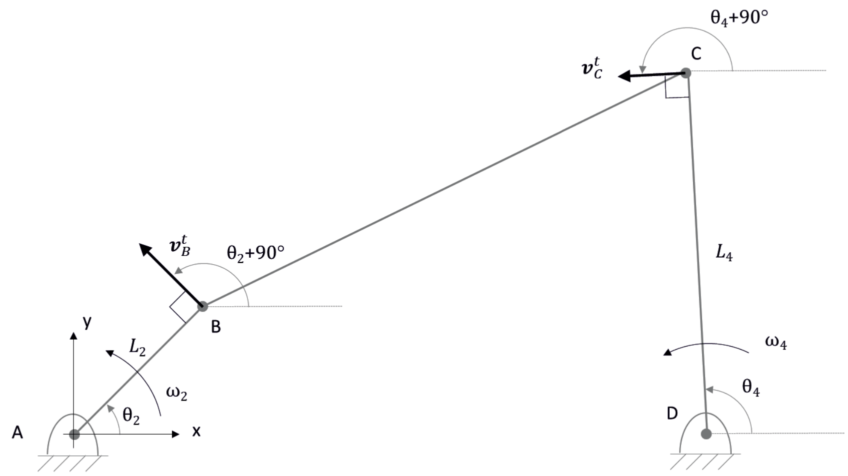

Figure 4: General velocity analysis of a four-bar mechanism

The direction of the tangential acceleration is perpendicular to the line between the point of interest and the point about which the link is rotating in the direction of rotation if the link is accelerating; it is opposite to the direction of rotation if the link is decelerating, see Figure 5. The direction of the normal acceleration is toward the point of rotation, see Figure 5. Acceleration of a point not on a link in pure rotation utilizes relative acceleration analysis techniques; the reader is directed to a kinematic textbook for a full discussion.

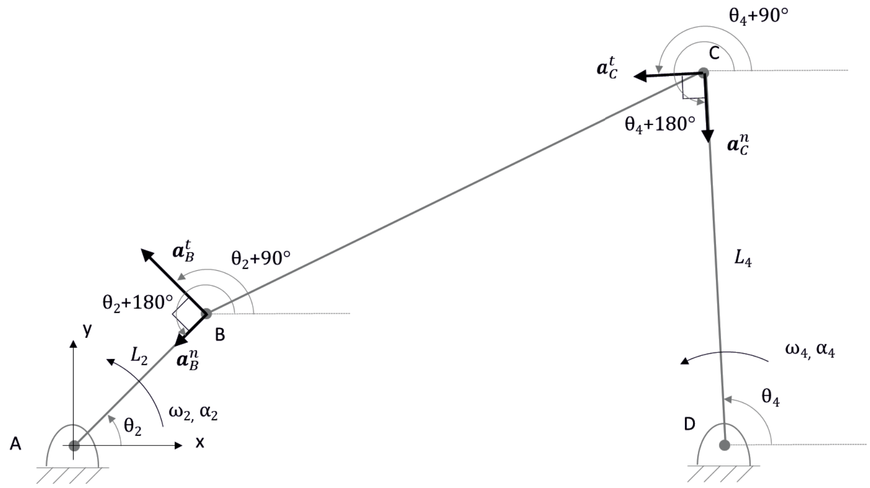

Figure 5. General acceleration analysis of a four-bar mechanism

2. Teaching Methods

The four-bar kinematic analyses described briefly in the previous section requires the integration of engineering dynamics with intermediate level math competencies (geometry, trigonometry, and vector algebra). Challenges that students face when approaching this type of kinematic analysis are clustered in three areas:

- Spatially orienting the various links of the four-bar mechanism relative to one another,
- Visualizing the motion of the links and joints as the four-bar mechanism changes configurations and thereby determining the vector directions for velocity and acceleration components, and
- Employing intermediate geometry, trigonometry, and vector algebra math skills to compute the kinematic analysis solution.

The following sections describe two teaching method approaches used in back-to-back semesters. Comparative results and instructor observations for each semester are then presented.

2.1. First Semester: "Traditional" Method

The teaching method utilized in the first semester relied on a traditional lecture based delivery system of analytical solution methods. Students were instructed on how to generate hand sketches of a four-bar mechanism using a ruler and a drawing compass. Hand calculations were then completed for a given four-bar mechanism (the same mechanism for the entire class) at a given configuration angle with a known angular velocity and angular acceleration of the input link. The students completed the hand calculations and compared the position analysis results to measurements made on their hand drawn sketch. A second configuration was then specified, generating a second hand sketch as well as a complete second set of hand calculations. Displacement values were then calculated and compared to measurements taken between the two hand drawings. In addition to hand calculations, spreadsheet software (e.g. Excel) was introduced and taught as an efficient means to complete the repetitive calculations for many different input angles. Representative results for a spreadsheet analysis are shown in Figure 6.

Based on current research on how learning happens (Felder, 2016), the outcome of this teaching method is not entirely surprising. The instructor observed that this approach was time-intensive and that not all students utilized their hand sketches to maximum potential (if at all) to directly check the calculated results of their position and displacement analyses. Many students also failed to understand how the hand sketches could be used to determine the directions of velocity and acceleration vectors. The connection between the analysis calculations and the reality of how the four-bar mechanism moved was not being made by the students. The instructor's takeaway from using traditional, passive lecture based teaching methods was that the student's understanding of kinematic analysis was not effectively communicated. A different approach toward teaching the course material was necessary.

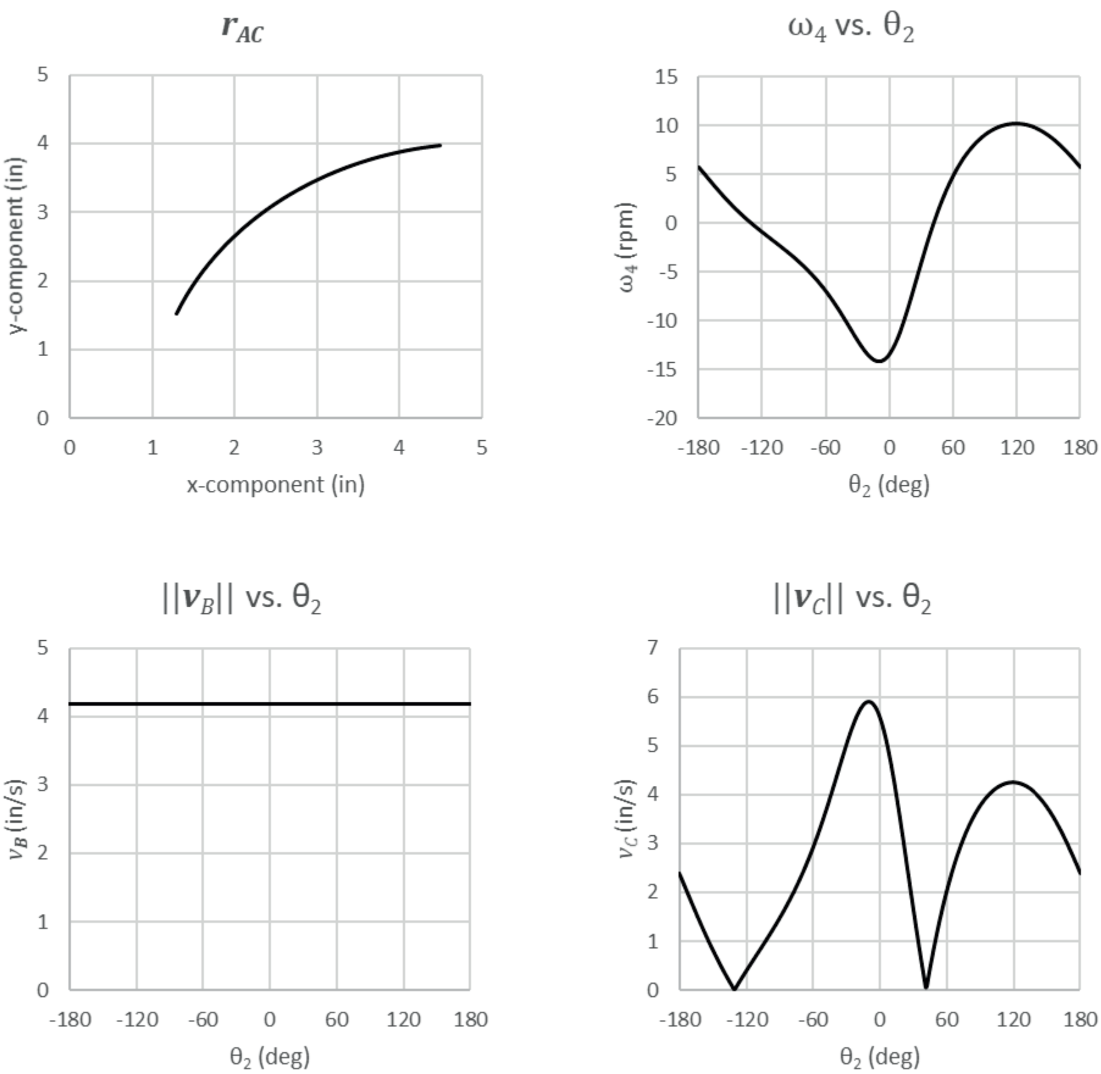

Figure 6. Representative spreadsheet kinematic results for a four-bar mechanism

2.2. Second Semester: Active Learning Method

The teaching method utilized in the second semester adopted active learning approaches. This method of teaching differs from passive learning techniques, such as traditional lecture, in that active learning attempts to create situations or "learning experiences in which the students are thinking about the subject matter" instead of merely observing (McKeachie, 2006). In active learning, one learns and begins to master the material by doing, engaging, and practicing the concepts (Felder, 2016). To better facilitate an active learning experience, each student was given the dimensions for a unique four-bar mechanism. They were provided with supplies and access to the School of Engineering's Makerspace to construct and assemble their own four-bar mechanism; see Figure 7 for an exemplar mechanism. The students used their physical four-bar mechanisms instead of hand-drawn sketches to compare to hand and spreadsheet calculations. The results of the kinematic analyses were the same outputs as in the previous semester (see Figure 6). But since each student had unique dimensions, they had their own set of results which were compared with classmates; this facilitated classroom discussion on what caused the kinematic differences. Discussions amongst students led to inquiry and reflection; hallmarks of effective learning (Felder, 2016).

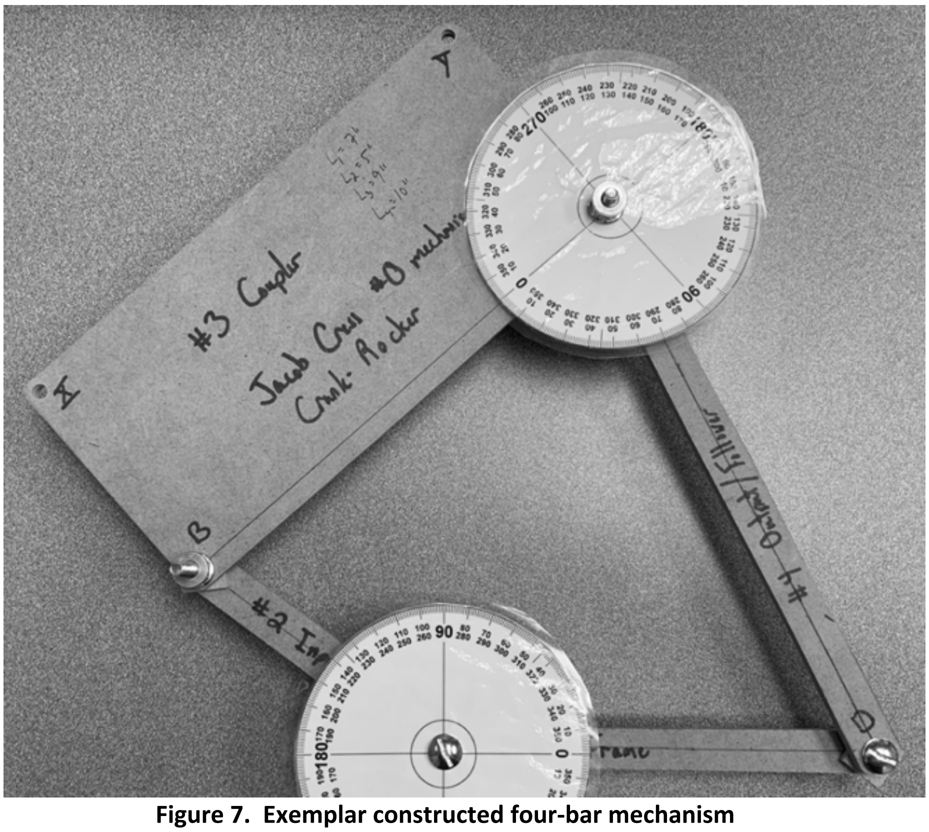

Figure 7. Exemplar constructed four-bar mechanism

The primary benefit of having a physical model of their four-bar mechanism was that the students could manipulate it through a full range of motion. This gave them the ability to better visualize and anticipate how the four-bar would move in different configurations. The four-bar mechanism could be positioned in a given configuration, points of interest marked or measured, and then compared to analysis results. The direction of velocity and acceleration vector components were more intuitively identified and how they changed as the mechanism moved to new configurations was better understood. Students frequently brought their four-bar mechanisms to class to manipulate during class discussions and to compare/contrast with classmates.

Instructor observations during the second semester with active learning indicated that students had a better understanding of the fundamental motion that a four-bar exhibits. There were fewer questions on basic concepts such as "how do I calculate the displacement of a point", "what direction will the tangential velocity act", or "why does the magnitude of angular acceleration go to zero mid-throw on a rocker arm". Instead, students were better equipped to probe into design questions. Inquiry into higher complexity knowledge increased.

Student evaluations of using the four-bar mechanism indicated that it was more beneficial during position and displacement analyses. On average, the students agreed with the statement (averaging 4 on a scale of 1 = strongly disagree to 5 = strongly agree) that having the position and displacement analysis assignments based upon their four-bar mechanism helped to visualize the motion. The velocity analysis benefit was less pronounced earning an average of 3.6 (between neutral and agree). Overall, students gave an average score of 4.2 to the question of whether they believed their understanding of kinematic analysis was improved because of the constructed four-bar mechanism.

2.3. Learning Outcome Comparison

A quantitative comparison of learning outcome achievement is based upon exam grades earned for the kinematic analysis module. Figure 8 and Table 1 presents the results for each semester. An Anderson Darling Statistical hypothesis test indicates that the data is reasonably normally distributed and that with a 90% confidence ($p = 0.074$) the mean of the second semester test results is greater than the mean of the first semester test results.

Therefore, the effect of implementing the student constructed four-bar mechanism was a net increase of 7.4% in the average test score for the kinematic analysis module. Additionally, two students retook the course the second semester; each student improved their kinematic analysis test performance between 2%-9%.

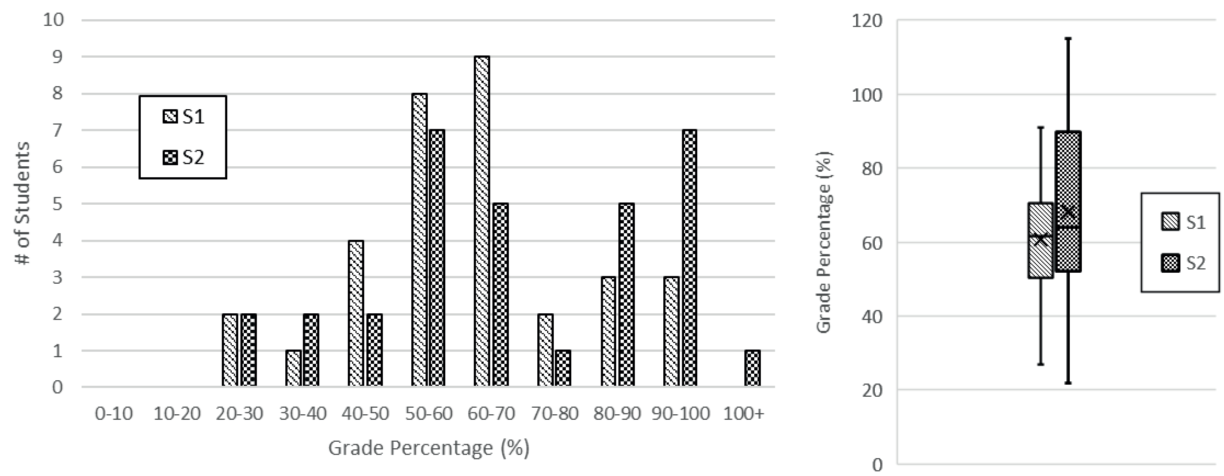

Figure 8. Comparison of semester test results

Table 1. Comparison of semester test statistics

	S1	S2	Δ
$\bar{x}$	**60.8%**	**68.2%**	**+7.4%**
σ	**17.3%**	**22.7%**	**---**
x_{max}	**91.0%**	**115.0%**	**+24.0%**
x_{min}	**27.0%**	**22.0%**	**-5.0%**
N	**32**	**32**	**---**

3. Conclusion

Kinematic analysis of a four-bar mechanism brings together skill sets in the areas of engineering dynamics and intermediate math. The results comparing the achievement of learning outcomes with and without active learning teaching methods (in the form of a student constructed four-bar mechanism) demonstrate a statistically significant improvement when active learning methods are implemented. This finding aligns with learning method research (Felder, 2016; McKeachie, 2006). Additionally, student self-assessment indicates a better learning outcome with the constructed four-bar mechanism. Further integration of physical and CAD simulated models is warranted to further improve student success toward the course specified learning objectives.

4. References

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A Variation of the Network Flow Algorithm to Optimize the Diversity of Project Groups

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Abstract

Research has shown that the amount of diversity within project groups has an effect on how well groups perform. In particular, groups that are balanced with respect to gender, race, national origin, and social background tend to be more creative, more productive, and perform better on average than non-diversified groups (Hunt 2015, Hunt 2018). Therefore the assignment of employees to project groups must also take into account the sub-goal of diversification during the decision making process (in addition to hard constraints such as suitable skill level of an employee to even qualify for membership in a group.) The additional constraints this imposes on the optimization problem of finding the best group composition can be a considerable challenge for management. In this paper, we present a new variation of a classical network flow algorithm to solve this problem optimally. We show the results of an application area where optimal groups have been formed that work together. The results have been obtained by the software implementation of our algorithm called "NF Group Diversity".

1. Introduction

The motivation for this paper is based on the question "Why do we want diverse groups?" What are the reasons for having diversity in project groups? Or similarly, what are the reasons for having diversity in a classroom? One reason is given in a McKinsey study (Hunt 2015). It found that companies that were in the top 75 percent for ethnic and racial management diversity had profits that were 35 percent higher than those of their industry peers. In addition, companies often can increase their creativity by encouraging diverse opinions and perspectives.

However, managing a diverse group presents numerous challenges for management (Shaban 2016, Saxena 2014). The focus of this paper is to support management with a tool to optimally assign employees from a pool of employees to project groups in such a way that the employees have the skills to work in their assigned group and also to ensure diverse groups at the same time.

To accomplish this we present a new variation of a classical network flow algorithm to match employees from a set E (the employee pool) with open positions in a set of project groups T (teams), such that every employee from E is matched to exactly one project group from T. Every employee has associated with it a skill-preference list which identifies project groups suitable for the employee's skill level. The overall quality of the assignment depends on the extent to which the skill-preferences of the employees are met. Employees also have a set of binary attributes associated with them which hold information about gender, whether they belong to a racial minority, or similar information deemed important for diversity. There is a hard constraint that all project groups should eventually hold the targeted number of employees. Furthermore, there are various additional constraints that promote that project groups contain a mix of employees with certain binary attribute values. We can optimally solve the resulting bipartite matching problem by reducing it to the network flow problem. We successfully designed, implemented and tested the proposed algorithm in a computer software program named "NF Group Diversity".

Please note that the algorithm and software described here helps decision makers to form balanced and diversified groups from a larger pool of individuals (e.g., employees). It is an assignment/matching algorithm, which distributes what we have into heterogeneous groups. If our overall pool of individuals has no or limited diversity to begin with, then there is not much that this algorithm can do for you! There have been several recent studies that suggest strategies on how to obtain a diverse pool of individuals (O'Brien 2015, Hunt 2018), so the reader interested in this type of problem is referred to these.

This paper is organized as follows. We start with a mathematically precise specification of the problem to be solved. Then we provide a description and graphical illustrations of the proposed algorithm that solves the problem. Then we provide one example application area in which the algorithm has been applied successfully. The paper concludes with recommendations and suggested future improvements and variations of the algorithm.

2. Problem Specification

Task: Match employees from a set $\boldsymbol{E=\{a,b,c,...\}}$ (the employee pool) with open positions (seats) $\boldsymbol{S=\{s_1, s_2, ..., s_n\}}$ in a set of project groups $\boldsymbol{T=\{A,B,...\}}$ (teams), such that every employee from $\boldsymbol{E}$ is matched to at most one project group from $\boldsymbol{T}$.

Every employee $\boldsymbol{e}$ from $\boldsymbol{E}$ has associated with her a skill-preference set $\boldsymbol{\{c_1, c_2, ..., c_k\}}$ which identifies project groups suitable for the employee's skill level. There is the hard constraint that the employee must have the skill set to participate in the assigned team.

Additional constraints reflect the fact that we promote that project groups contain a diverse mix of employees with certain binary attribute values (e.g., male/female). An example target might be to ensure that the female-to-male ratio is approximately the same in each team, thus ensuring diverse teams which reflect the female-to-male ratio of the overall employee pool. The screenshot in Fig. 5 shows such an approach for an employee pool that is roughly 30% male and 70% female. In that example, we specified a "slack", i.e., a maximum deviation from the optimal gender ratio of 0.1=10%. Therefore, a solution to this problem instance (if one exists) will have a male ratio from the interval [30%-10%;30%+10%] = [20%;40%] and the corresponding female ratio from [60%;80%]. The algorithm can easily be adjusted to reflect other diversity goals by changing the color labels of the seat nodes in phase 2 of the algorithm.

The objective of this optimization problem is to maximize the number of employees assigned to teams while respecting all imposed constraints.

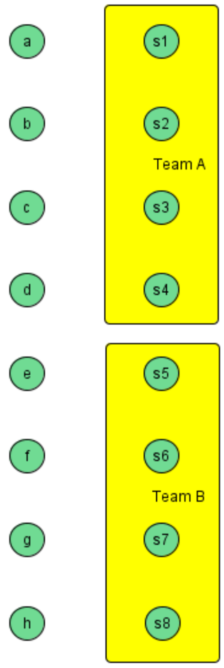

Figure 1. A small Problem Instance

We build a graph model that initially consists of a vertex set that is made up of the set of employees E and the set of seats S as defined above. For illustration purposes an example instance is visualized in Figure 1, where eight employees are to be assigned to two teams of size four each.

3. Description of the Algorithm

The proposed algorithm consists of four phases. There are two novel ideas that are presented in phase 1 and phase 2 of the algorithm. Phases 3 and 4 are an application of existing algorithms that are well-known in the computer science and operations research literature (Cormen et al. 2009, Papadimitriou and Steiglitz 1982).

Phase 1: Recall that every employee has associated with it a skill-preference set $\{c_1, c_2, ..., c_k\}$ which identifies project groups suitable for the employee's skill level. We now introduce an edge from an employee to each seat of a team, if the employee has the skills to work in that team.

Phase 2: Characterize (reserve), e.g., by color-coding, each seat in a team as "black", or "white", or "grey" (meaning individuals with either diversity feature can get the seat.) Remove those edges introduced in Phase 1 where the diversity feature value of the employee is incompatible with that of the seat. (Note that by increasing/decreasing the number of "grey" seats we can soften/harden the diversity constraints that we want to achieve. In the example later shown in the screenshot in Fig.5 this is accomplished by adjusting the parameter "Max. Deviation from Gender Ratio".)

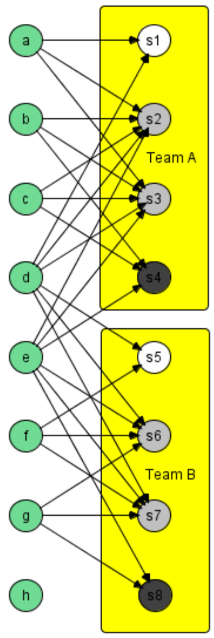

Figure 2. Problem Instance after Phase 2 of the Algorithm

The problem instance shown in Figure 2 shows the resulting graph after phase 2 of the algorithm. For example, employee ***a*** has skills that qualify her for membership in Team ***A*** (but not Team ***B***); moreover, to enforce diversity, employee ***a*** is allowed to occupy the white-colored seat ***s1***, or the grey-colored seats ***s2*** or ***s3***, but not the black-colored seat ***s4***. Therefore, there are three edges originating from vertex ***a*** to the vertices ***s1***, ***s2***, and ***s3***. Note that employee ***h*** does not have the skill set to qualify for membership in either team, thus there are no edges originating from vertex ***h***.

Phase 3: Reduce the resulting Bipartite Matching Problem to the Max-Flow Problem by introducing a source node which connects to all employee vertices ***E*** and a sink node to which all seat vertices ***S*** connect to (Papadimitriou and Steiglitz, 1982). The resulting graph is shown in Figure 3.

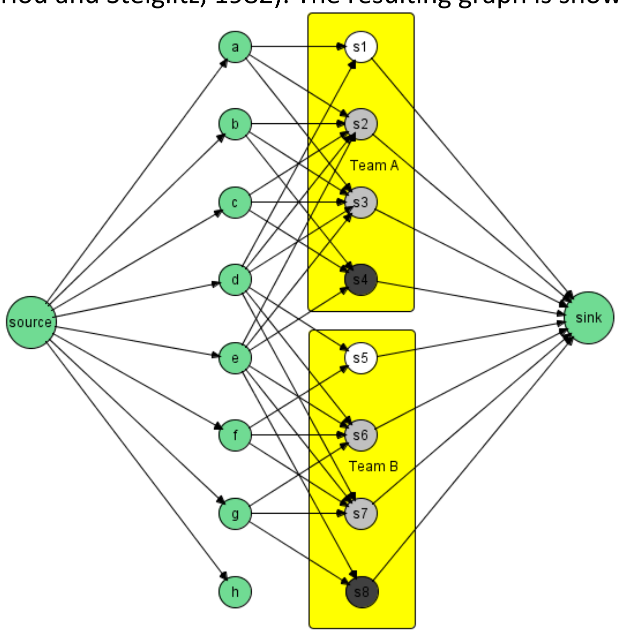

Figure 3. Problem Instance after Phase 3 of the Algorithm

Phase 4: Build an assignment by running a bipartite matching algorithm based on a suitable MaxFlow algorithm: the original algorithm (Ford and Fulkerson, 1962) or an improved version (Edmonds and Karp, 1972), or a more recent variation that solves this well-studied problem.

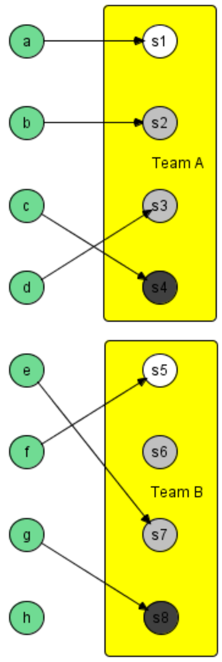

Figure 4. Solved Problem Instance after Phase 4 of the Algorithm

Figure 4 shows the output of phase 4 of the algorithm; for clarity, the source and sink nodes have been removed. In this case, the maximum flow from the source to the sink has a value of 7, and the edges through which this flow takes place (and only these 7 edges) are shown in Figure 4. For example, employee ***a*** has been assigned to seat ***s1*** in team ***A***, employee ***g*** has been assigned to seat ***s8*** in team ***B***, and seat ***s6*** has not been assigned to any employee, because of the lack of a skilled employee to occupy the seat. Note that our algorithm always yields a resulting assignment that is provably optimal (in the sense that the maximum number of seats are assigned) with respect to the constraints imposed. In the small example shown in Figure 3 it is probably impossible to find a flow of value 8. The max flow value is 7.

This algorithm is efficient for all practical numbers of employees and seats. The graph it operates on has $|V|=|E| + |S| + 2$ vertices, and up to $O(ES)$ edges. The time complexity of the algorithm is determined by phase 4 of the algorithm, which takes $O(V(ES)^2)$ if the Edmonds-Karp algorithm is chosen. In our software implementation, the program completes its assignment very quickly, even when the number of employees and seats is in the magnitude of 1000. The partial output of the software for 536 employees and 536 seats is shown in the screenshot of Figure 5 and it has been computed in less than one second on a standard laptop computer.

4. Application: Project Groups

In one practical application of our algorithm, we had an existing employee pool of $|E|$=99 members that had some diversity in several dimensions. Some employees were very skilled and could join a large number of project groups, whereas others were less skilled and could join only a small number of project groups (Table 1).

Table 1. Data of the Employee Pool

Employee ID	Sex	Culture	Skill 1	Skill 2	...	Skill k
a	M	US	A	B	...	K
b	F	US	B	C	...	L
c	M	Int	A	D		
...						

Each team had a limited number of positions (11 seats), and because of budget constraints there was a strict company policy that teams cannot have excess team members. In order to obtain diversity in all teams, we imposed a gender balance constraint and a cultural background (nationality) constraint for most of the seats in a team. Two seats in each team were colored "grey" which softened the diversity constraints imposed on this problem so that all seats could be filled with employees. It is worth to note that with 0% of "grey" seats an optimal matching left some seats unoccupied, which was undesirable for management, so we softened the diversity constraints by repeatedly increasing the number of "grey" seats and re-running the algorithm until we arrived at a solution where all seats were occupied. In this application employees were assigned to at most one team. In the end we achieved pretty well-balanced teams (Table 2) where the female:male ratio was between 18:82 and 37:63 for all teams and coincidentally similar results were obtained for the make-up of the cultural background of each team, where each team roughly had a similar cultural background ratio as the employee pool as a whole.

A theoretical optimum for our employee pool of 99 employees with 27 (27.27%) female members and 31 (31.31%) non-US members that need to be assigned to $|T|=9$ teams of 11 employees each would look as follows: each team would have 3.0 female members, and 3.44 non-US members. This theoretical optimum has not been achieved because of the nature of the input data in terms of the distribution of employee skill level and also because the numbers of team members must always be integers, but with the aforementioned slack we have achieved these results with 2 "grey" seats: Each of the 9 teams had at least 2 and at most 4 female members, and at least 2 and at most 4 non-US members.

In summary, for this application, the algorithm successfully computed an automated assignment of employees to teams, where each employee had the skills needed to work in the assigned team, and there were no longer "all U.S. male" teams as had been the case in the past with a traditional (manual) approach to assigning teams. Of particular practical value turned out to be the fact that for each minority group (female, non-US) the algorithm could ensure at least two members per team from that minority, which avoided the "outsider" feeling that might have arisen if there would have been only a single member from a particular minority.

Table 2. Output of the Algorithm (shown in last column)

Employee	Sex	Culture	Skill 1	Skill 2	...	Skill k	**Assigned Team**
a	M	US	A	B	...	K	**A**
b	F	US	B	C	...	L	**C**
c	M	Int (non-US)	A	D			**D**
...							

5. Conclusions and Future Work

The algorithm introduced in this paper and the software "NF Group Diversity" that implements it (see screenshot in Figure 5) provide an efficient way to support decision makers in finding the best team composition with respect to employee skills and employee diversity. The algorithm should be understood as a building block, which can – often easily - be customized to reflect alternative company policies and diversity goals, e.g., by simply repainting the seats.

Data of the employee pool (such as in Table 1) is delivered to the software in the form of an input file (called input.txt in the screenshot of Figure 5), and then a comprehensive output file with content such as in Table 2 (called output.txt in the screenshot of Figure 5, enriched with additional statistical information) is produced by NF Group Diversity. Improvements of this basic GUI are currently a work in progress.

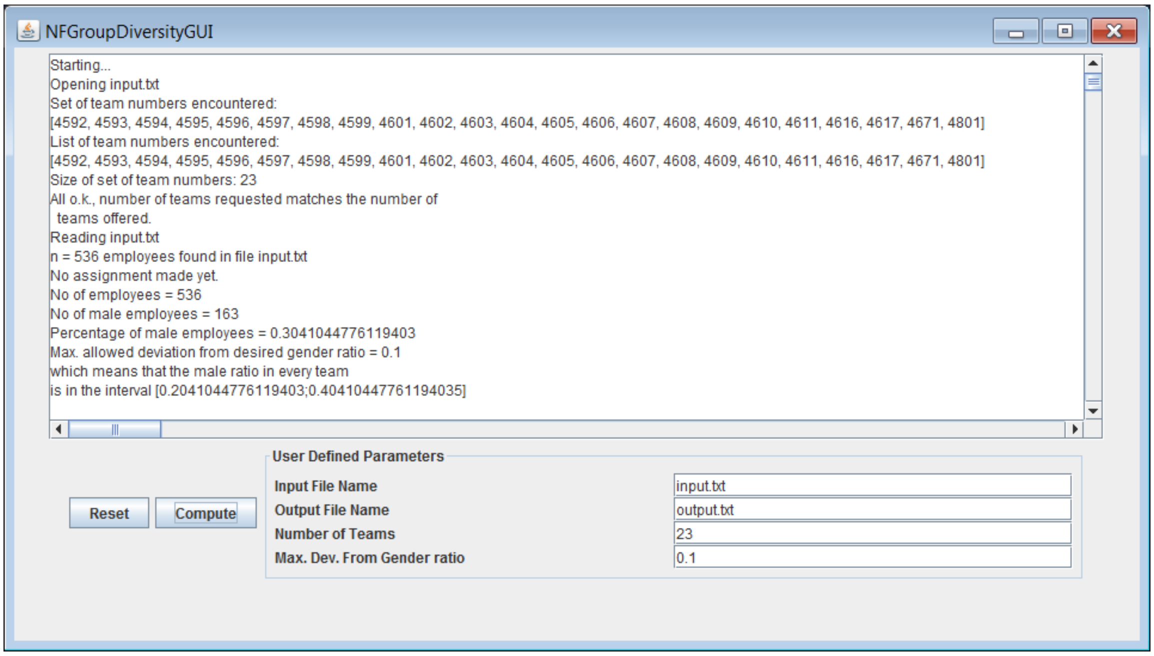

Figure 5. Screenshot of software "NF Group Diversity"

More future work is needed to generalize the algorithm and the software NF Group Diversity so that it can handle non-binary diversity features (say age), and to improve how the seats are colored if there are multiple diversity features to be considered simultaneously. Finally, further efficiency improvements are possible by choosing a more efficient network-flow algorithm in phase 4 of our algorithm.

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A Genetic Algorithm for Battery-Based Energy Storage Transportation Using Railway

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Abstract

The use of renewable energy sources has increased significantly in the past few years. Due to the intermittent nature of the renewable energy sources, planning and distribution of this energy is considered a challenging process. Energy storage systems have a great potential towards these challenges as it can store energy from different sources and then distribute it to regions with high demand such as in the case of Battery Based Energy Storage System. In this paper, the impact of railway Battery Based Energy Storage System on the power grid is considered. A genetic algorithm is proposed for solving the dispatching of rechargeable battery-based energy storage train vehicles to satisfy the charging/discharging requirements of rural areas not directly connected to the power grid due to being temporary locations such as rural cities under construction and military rural campuses. A multi-objective model is proposed that has the following objectives: 1) to minimize the transportation cost associated with the train route; and 2) to minimize the number of Battery Storage vehicles. A Genetic Algorithm is developed and tested using numerical examples. The results show the effectiveness of the proposed algorithm in providing good solutions using the minimum number of Battery storage vehicles in a cost-effective energy distribution system.

1. Introduction

Energy has become a crucial element for sustainable development. Renewable energy, as an important source of energy, has been integrated in the power grid to provide a cleaner and more sustainable form of energy. The use of solar energy, wind energy, and other renewable energy power generation is gradually increasing. In this paper, the use of renewable energy is integrated in the electric power grid using Battery-Based energy Storage Systems (BBSS). This paper considers the use of railway network to transport the BBSS from the generators to areas with high demand or areas that are not linked with transmission lines. The BBSS stores energy from renewable energy sites and, by using the railway systems, transmits it to regions where such energy has the highest potential for grid management.

This is especially important in three cases: 1) the generating sites are too far away from the consumption sites and are already connected to railroads services; 2) the consumption sites are far away and not linked to the generating sites, but are connected to railroads services; and/or 3) the consumption (or generating) sites are dynamic with no fixed location, but accessible via the railroads. In other words, the problem is important when there is already a railroad network connecting the sites, meanwhile, the cost of connecting them to the same electric grids is high.

The paper is structured as follows. Section 2 discusses the literature related to the problem. Section 3 discusses the problem definition and the mathematical model for the problem. Section 4 introduces the proposed genetic algorithm. Section 5 shows the numerical experimentation conducted to test the effectiveness of the proposed model. Finally, section 6 summarizes the important findings and provides conclusions.

2. Literature Review

The energy distribution problem has attracted the research attention in the past few years. Xie et al. (2019) studied the impact of renewable energy on the power supply chain. They studied the power market and analyzed the different power supply chain operation modes. They discussed the optimal mode selection for renewable energy generator and power grid in different situations. Aflaki & Netessine (Aflaki & Netessine, 2017) analyzed the incentives for investing in the capacity to generate renewable electricity. They modeled the trade-off between renewable and nonrenewable from the investment cost, the nature of energy supply, fuel expenditures and carbon emission costs. They concluded that market liberalization may reduce investment in renewable capacity while increasing the overall system's cost and emissions; and that the intermittency of renewable technologies drives the effectiveness of carbon pricing mechanisms.

Kong et al. (2017) studied the capacity investment strategy under volatile electricity spot price when renewable energy penetration rate is low, taking into account whether the distributions of renewable energy source electricity and electricity spot price are independent or dependent. Kong et al. (2018) modeled the intermittence of wind power as uncertain supply, and develops a capacity-investment model under the uncertainties of both supply and demand. Their results show that optimal capacity investment is inversely related to priority dispatch elasticity. They also noticed that the profit from power generation is always higher when adopting the abandoned power management strategy. Fernando & Yahya (2015) studied the challenges of renewable energy management implementation and how firms manage the low carbon issue in their supply chains. Jiaping et al. (2017) studied the decisions on capacity investment for power producers facing a location problem in dual-echelon renewable energy source power supply chain. They assumed that demand and supply are uncertain, while the grid-connected power price is fixed. The problem was modeled as a Stackelberg game. They analyzed the impact of intermittence on profit distribution and risk sharing and compared between centralized and decentralized capacity investment decisions. They found that site candidates with higher market value should be given priority to invest under centralized decisions, while candidates with lower equivalent cost should be invested in first under conditions of a decentralized decision.

Sunar & Birge (2015) considered a day-ahead electricity market that consists of multiple competing renewable firms and conventional firms in a discrete-time setting. If a firm produces less than its cleared day-ahead commitment, the firm pays an undersupply penalty in proportion to its underproduction. The purpose of an undersupply penalty is to improve reliability by motivating each firm to commit to quantities it can produce in the following day. They proved that in equilibrium, imposing or increasing a market-based undersupply penalty rate in a period can result in a strictly larger renewable energy commitment at all prices in the associated day-ahead market, and can lead to lower equilibrium reliability in all periods with probability. Mahani et al. (2017) considered multiple energy storage nodes distributed over a power distribution network, the problem was to optimally allocate these nodes over the distribution network and to create day-ahead plans according to planned applications. Zaeim-Kohan et al. (2018) propose a multi-objective particle swarm optimization for transmission congestion management considering demand response programs (DRPs) and generation rescheduling. The objective functions included the Total operation/DR cost, the emission and the load increase of transmission lines. The proposed model was tested on two test systems (IEEE 30-bus and IEEE 118-bus test systems). Hemmati (2018) presented a unified stochastic planning on battery energy storage systems in electric power systems including wind power plants. He considered the cost of energy in the network, the investment-operational costs, and the lifetime of battery energy storage systems as objectives.

Sun et al. (2015) considered the battery-based energy storage transportation by railway transportation network. He adopted a time-space network model and integrated the hourly security-constrained unit commitment with vehicle routing problem. He used two cases to simulate the battery-based energy storage transportation. Lu and Li (2017) also considered the Energy Storage Transportation with the objective of minimizing the total system planning cost.

Barber et al. (2008) developed a Genetic Algorithm to solve the Train Timetabling Problem. The timetable for the new trains is obtained with a Genetic Algorithm (GA) that includes a guided process to build the initial population. The proposed GA is tested using real instances obtained from the Spanish Manager of Railway Infrastructure (ADIF). The results showed that GA was able to explore the search space and led to good solutions in a short time. Sun el al. (2014) proposed a multi-objective optimization model for train routing on high-speed railway network to provide a better service. Beside the average travel time of trains, the model also considers energy consumption and user satisfaction. Based on this model, an improved GA was designed to solve the train routing problem. The simulation results demonstrate that the accurate algorithm is suitable for a small- scale network, while the improved genetic algorithm based on train control (GATC) applies to a large-scale network.

The objective of this paper is to plan the transportation of battery storage system from generators or renewable energy sources to consumption nodes on large scale networks using railway system. The paper proposes a genetic algorithm model to solve the problem and be able to find:

1. The assignment of load nodes to generator nodes
2. Number of trains required
3. Number of batteries on each train
4. Best route for each train
5. Min transportation cost

3. Problem Definition

This section describes the problem and the assumptions considered in this model. For the railway network shown in Figure 1 where the nodes represent consumption/generation points and the arcs represent the rail road route from one node to another. The demand forecast of consumption nodes is known for a given time horizon. Each generator has a maximum capacity. The problem is to supply the consumption nodes with the required power. Battery Based storage system is used to store the power from the generator nodes and supply the consumption nodes. The batteries are transported using trains on the available railway system. The battery can stay idle at any point or it can be charged/discharged. The objective is to schedule the trains and determine the number of batteries needed in each train for a given planning horizon to satisfy the given demand.

The assumptions of the developed model are as follows:

1. The model plans for a given planning horizon.
2. Demand for each period within the planning horizon is known for all load nodes.

3. Max generating capacity for each generator is known.
4. Transportation time between nodes is known.
5. Charging and discharging rates are known and assumed to be constant
6. Max capacity of battery is known

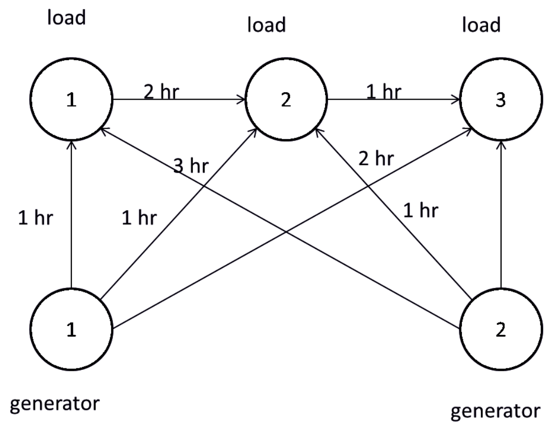

Figure 1. Railway network under consideration

To formulate the problem, the network is further divided into a time interval divisible by all the links duration. For example, the network shown in figure 1 could be divided into one hour interval, in this case, the link joining generator 2 to load node 1 is further divided into 3 one hour links with 2 auxiliary nodes added in between.

For a set of nodes *I* and their auxiliary Nodes *I'* connected by set of arcs *A* where $A=\{(i,j): i \text{ and } j \in I \cup I'\}$. among *I* there is a subset *G* of nodes with generators where $G \subset I$. There is *N* train engines available, each can pull up to N^c battery vehicles. Battery vehicles are charged at the generator nodes. Consider a planning horizon *K* which is a multiple of the time interval used in the auxiliary network. The problem is to supply each node by its power requirement in each time period minimizing both of the transportation cost and the number of battery vehicles required.

The following nomenclature is used in the model:

Parameters

I Set of nodes

I' Set of auxiliary nodes

G generators nodes set where $G \subset I$

N number of trains

N^c Number of battery vehicles that can be stowed by a train engine

A set of connecting arcs

K time horizon, must by a multiple of the time interval used in the auxiliary network

c_{ij} cost of transporting a battery vehicle from node *i* to node *j*.

D_{jk} demand of node *j* at time *k*.

d_1 discharge rate for a time interval when in travel

d_2 discharge rate for a time interval when idle at a node

d_3 discharge rate for a time interval when in discharging at a node or charging at a generator

Variables

x_{fijk} binary decision variable of whether vehicle *f* visits *j* just after *i* at time *k*

F number of battery vehicles required

y_{fik} binary decision variable of whether vehicle *f* is used in charging/discharging node *i* in time *k*

Q_{fk} charge of vehicle *f* at time *k*

Q_f^m max charge of vehicle *f*

Indices

i,j index of nodes from $I \cup I'$

f index of the battery

Formulation

Objective 1: Min $\sum_{i \in I \cup I'} \sum_{j \in I \cup I'} \sum_{f=1}^{F} \sum_{k=1}^{K} c_{ij} x_{fijk}$ (1)

Objective 2: Min F (2)

Subject to:

$$\sum_{i \in I \cup I'} \sum_{i \in I \cup I'} x_{fijk} = 1 \qquad \forall k \le K, f \le F \qquad (3)$$

$$\sum_{i \in I \cup I'} x_{fijk} = \sum_{i \in I \cup I'} x_{fjik+1} + x_{fjjk+1} \qquad \forall k \le K, f \le F, j \in I \cup I' \qquad (4)$$

$$\sum_{f=1}^{F} \sum_{j \in I \cup I'} Q_{fk} x_{fjk} x_{fijk} \ge D_{jk} \qquad \forall k \le K, f \le F, j \in I \cup I' \qquad (5)$$

$$Q_{fk+1} = min\,(Q_{fk} - d_1 \sum_{i \in I \cup I'} \sum_{j \in I \cup I', i \ne j} x_{fijk} - d_2 \sum_{i \in I \cup I'} x_{fiik} - d_3 \sum_{i \in \frac{I}{G}} y_{fiik} x_{fiik} + d_3 \sum_{i \in G} y_{fiik} x_{fiik}, Q_f^m) \qquad \forall k \le K, f \le F \qquad (6)$$

$$Q_{fk+1} = max(Q_{fk} - d_1 \sum_{i \in I \cup I'} \sum_{j \in I \cup I', i \ne j} x_{fijk} - d_2 \sum_{i \in I \cup I'} x_{fiik} - d_3 \sum_{i \in \frac{I}{G}} y_{fiik} x_{fiik} + d_3 \sum_{i \in G} y_{fiik} x_{fiik}, 0) \qquad \forall k \le K, f \le F \qquad (7)$$

$$\sum_{f=0}^{F} \sum_{i \in I \cup I'} \sum_{j \in I \cup I', i \ne j} x_{fjik} \le F \qquad \forall k \le K \qquad (8)$$

$$\sum_{k=0}^{L+1}\sum_{f=0}^{F}\sum_{j\in I\cup I^{'},i\neq j} x_{fijk} \leq \sum_{k=0}^{L}\sum_{f=0}^{F}\sum_{j\in I\cup I^{'},i\neq j} x_{fjik} + \sum_{f=0}^{F} x_{fii0} \quad \forall L < K, i \in G \qquad (9)$$

$$\sum_{f=1}^{F} x_{fjik} \leq N^{c} \quad \forall k \leq K, f \leq F, i \in j \in I \cup I^{'}, j \in I \cup I^{'} \qquad (10)$$

$$\sum_{i\in I\cup I^{'}}\sum_{j\in I\cup I^{'}}\left(\min\left(1, \sum_{f=1}^{F} x_{fijk}\right)\right) \leq N \quad \forall k \leq K \qquad (11)$$

The multi-objective model has two objectives: equation (1) minimizes the total cost of transporting the vehicles and equation (2) minimizes the number of vehicles. Equations (3) restrict the movement of a vehicle to one source/destination nodes at a given time. In equations (4), whenever a vehicle visits a node at time k, it must either stay at the same node or move to a successive node in k+1. In equations (5), the total power of all the vehicles at node j at time k is greater than the required power. In equations 6 and 7, the charge of a vehicle at time k+1 equals its charge at time k minus losses in movement, in idle, and in discharging to nodes plus charging from the generators. Equations 6 and 7 limit the max charge to the battery capacity and the minimum to be zero.

Equations (8) restrict the number of batteries to no more than F batteries. Equations (9) ensure that at any time interval, the cumulative total number of batteries coming out from the start is less than or equal to what were initially at the generator plus the number of batteries visited the generator in between. Equations (10) restrict the number of batteries used at any interval between two given nodes to be smaller than the trains' capacity. Equations (11) restrict the number of trains to be no more than the available trains at any time interval.

4. The Proposed Multi-Objective Solution Algorithm

Genetic Algorithms(GA) offer an attractive approach for effective rapid global search of large, non-linear solution spaces (Pardalos PM, Floudas CA., 2009). The trains scheduling GA model is formulated as a vehicle routing problem (VRP) in a time-space network (Yingyun Sun et al., 2015). The objective is to minimize the transportation cost and minimize the number of battery vehicles needed. The general procedure for the developed multi objective GA is shown in Figure 2. The GA starts with generating the initial population randomly as mentioned in section 4.1. Each chromosome in the initial population is evaluated by applying train assignment heuristic and using the fitness function. A new generation is formed from the elite chromosomes (best chromosomes in fitness function value), crossover children and mutated children. The same process is repeated until the stopping criteria is met which is the number of generations.

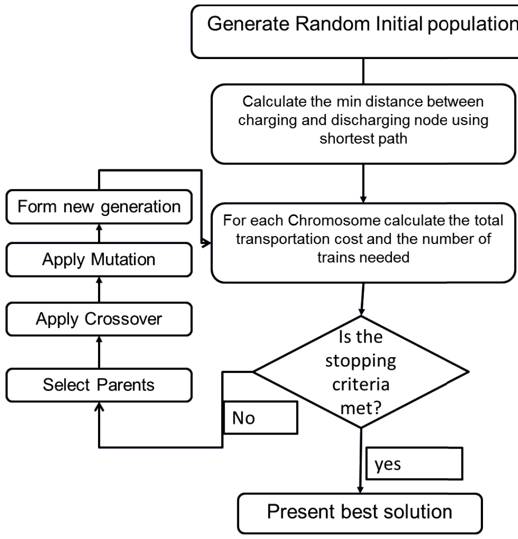

Figure 2. Flow chart of the developed model

4.1. Chromosome representation and Initial Population

The chromosome is divided into two parts as shown in figure 3. The number of genes in the first part of the Chromosome is equal to the number of trains available. Each gene represents the total power capacity of each available train (i.e., the number of batteries on this train multiplied by the battery capacity). In figure 3, the first cell means that a train with a total capacity of batteries of 200 MWh is available to use (i.e. 10 batteries each with a capacity 20 MWh). The second part of the chromosome represents the assignment of load nodes to generator nodes. The length of this part is equal to the number of load nodes that must be visited. For Each gene a random number is generated that represents the assigned generator that will supply the current load node (e.g., the fourth cell means that load node 4 will be supplied from generator node 1).

200	100	200	1	2	3	1	1

Figure 3. chromosome representation

The model allows for more than one train to be assigned to the same generator node. However, each train is allowed to visit only one generator once in the available time spam.

To evaluate the chromosomes, we propose a heuristic for train assignment to generator and load nodes (Algorithm 1). The first step in the assignment procedure is that for each generator node, a set of all nodes that are assigned to this generator is created from the chromosome. For each generator node (g) a train(N) is assigned. The train is charged at the generator node and travels to the load nodes assigned to this generator according to their order in the chromosome. If the time needed to charge the train batteries, travel to the node and discharge at that node is greater than time span allowed, then, a new train is assigned (N+1). A new train is also assigned if the remaining capacity of the batteries in the train before serving the load node is less than the demand at this load node. This train starts the journey from the generator to the rest of load nodes assigned to this generator.

When we apply the proposed algorithm on the chromosome shown in figure 4, we start by the first train and the first unassigned node. We start with train 1 which has a capacity of 200MWh (i.e., 10 batteries). The first unassigned node is node 1 which is assigned to generator 1. We then conclude that the nodes that can be possibly served by the current train are those assigned to generator 1 (i.e., nodes 1, 4 and 5). If the train has unused capacity capable of serving node one without violating the time requirement, then node one is assigned to train 1 and the next node assigned to the same generator is considered (node 4). Otherwise, the next train is considered.

In case node 1 is added, the requirement of node 4 is considered against the unused capacity in the first train along with the time requirement. If it can be feasibly served, node 4 is assigned to train 1. Otherwise, node 4 is dropped from the current possible nodes to be served by the current train and we look for the next candidate (i.e., node 5). Node 4 is then considered in train 2 and we keep iterating until all nodes are assigned to trains.

Algorithm 1: Train Assignment algorithm

1- Set g=1, N=1
2- Determine $LGset_g$ which is a set of all the load nodes(j) assigned to generator(g)
3- If $LGset_g$={ϕ} **then** go to step 6
4- Set $TLset_f$={ϕ}, $Tcap_f$=chrome(NT), $Time_{fg}$=charging time at (g)
5- For each load node(j) in $LGset_g$
  If demand of node j at time k (D_{jk})< $Tcap_N$ & $Time_{fg}$ + time from node i to j (t_{ij})+discharging time(L)<time horizon(k)
    Then $TLset_f$ ={ $TLset_f$, j}, $Time_{fg}$ = $Time_{fg}$ + time from node i to j (t_{ij})+discharging time(L)
    Otherwise N=N+1
    $TLset_f$ ={ j}, $Time_{fg}$ = charging time at (g)+time from node i to j (t_{ij})+discharging time(L)
6-If g<G **then** set g=g+1 and go to step 2 **Otherwise** go to step 7

The fitness function for the Proposed multi-objective GA model is minimizing the total transportation cost shown in Equation (12) and minimizing the number of battery vehicles needed as shown in Equation (13)

Objective 1: Min $\sum_{i \in I \cup I'} \sum_{j \in I \cup I'} \sum_{f=1}^{F} \sum_{k=1}^{K} c_{ij} x_{fijk}$ (12)

Objective 2: Min F (13)

The multi-objective GA finds the pareto front of the two objectives. This front keeps the non-dominated solutions and discards the dominated solutions. This allows the decision maker to choose the solution most suitable to the problem.

4.2. Parents Selection and Crossover

The parents are selected according to tournament selection. The Crossover used in the developed model is single point crossover. The parents are divided at the end of train capacity genes into two parts as shown in Figure 4 where the first part of the new child is taken from parent one(train capacities) and the second part from parent two (generators assignment to load nodes).

P1	**500**	**200**	**300**	**1**	**2**	**2**	**1**	**3**
P2	**400**	**300**	**100**	**4**	**3**	**3**	**1**	**2**
child	**500**	**200**	**300**	**4**	**3**	**3**	**1**	**2**

Figure 4. One-point crossover

4.3. One-Point Scramble Mutation

The mutation used in the proposed GA is one-point scramble mutation. In this mutation a binary number is generated randomly. If the selected number is equal to zero, the first part of the chromosome, which represents the trains capacity, is mutated by being completely randomly generated. On the other side, if the selected number is equal to one, the second part of the chromosome, which represents the route and the stations sequence, is mutated by randomly generating new genes for the route.

In the example shown in Figure 5, the random number is equal to one so the mutation happens to the second part of the chromosome by creating totally new genes. This method avoids being trapped in a local optimum.

Chromosome:

200	**100**	**200**	**4**	**3**	**3**	**1**	**2**

Mutated child:

200	**100**	**200**	**1**	**2**	**3**	**4**	**1**

Figure 5. One-point scramble mutation

5. Numerical Experimentation

To test the developed GA, two data set were generated 30 nodes(P30) and 90 nodes (P90). Table 1 shows the values of the two data sets parameters. The Genetic Algorithm Toolbox in Matlab 2016 is used to solve the test problems.

5.1. Results for P30 Nodes Data Set

The total number of nodes in this data set is 30 nodes, 22 of them represents the load nodes and 8 nodes represents generator nodes. The battery capacity used is 20 MWh which is equivalent to 50 feet standard rail car battery. The maximum number of batteries rail car that could be carried by a single train is 8 batteries. The time spam for the generated Schedule is 24 hours. The charging time and discharging time is 4hrs. The demand of load nodes is shown in Table 2 while the capacity of generators is shown in Table 3.

Table 1. The values of the numerical example

Parameters	P30	P90
Number of nodes (*I*)	30	90
Generators nodes (*G*)	6	40
Load Nodes (*L*)	24	50

Max Number of trains (*N*)	30	40
Number of battery vehicles (N^c)	8	8
Max Charge of Battery	20 MWh	50 MWh
Time horizon (*K*)	24 hr	24 hr
Charging and Discharging	4 hr	4 hr
Genetic Parameters	Value	Value
Population size	400	400
Generations	3000	3000
Crossover rate	0.7	0.7

Table 2: The Demand At Load Nodes

Node	Demand	Node	Demand
1	11	**12**	9
2	14	**13**	3
3	7	**14**	9
4	3	**15**	2
5	12	**16**	17
6	10	**17**	8
7	5	**18**	10
8	11	**19**	3
9	6	**20**	10
10	8	**21**	4
11	3	**22**	10

Table 3: Generator Nodes Capacity

Node	Capacity
1	80
2	55
3	50
4	80
5	80
6	50
7	80
8	55

To evaluate the effectiveness of the developed genetic algorithm the model is used for a single objective which is the transportation cost. Figure 5 shows that the model converges with the increase in generation number. To illustrate the multi-objective results, figure 6 shows the pareto front for the two objectives: the transportation cost and the number of battery vehicles. Figure 7 shows that the results of the model are consistent when tested on different runs.

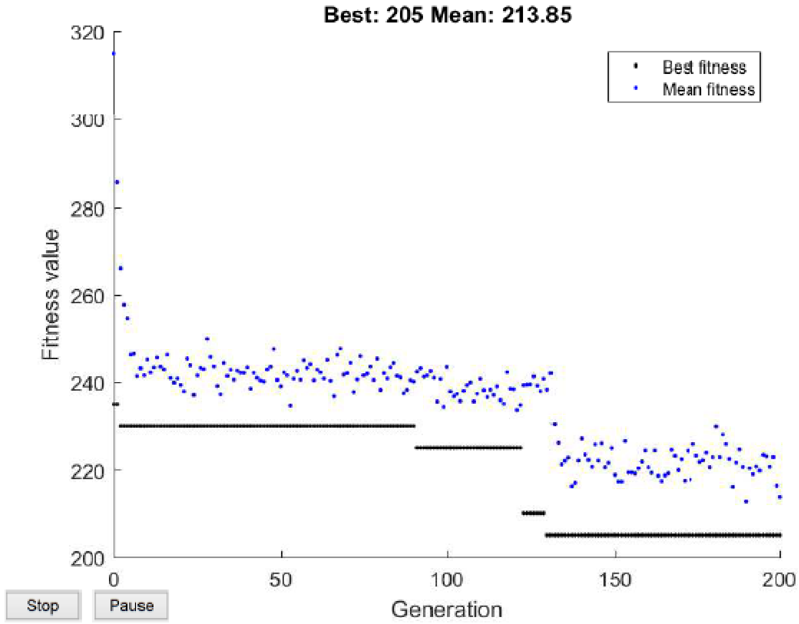

Figure 7. The best and the mean fitness value (transportation cost) plotted against generations for 30 node data set

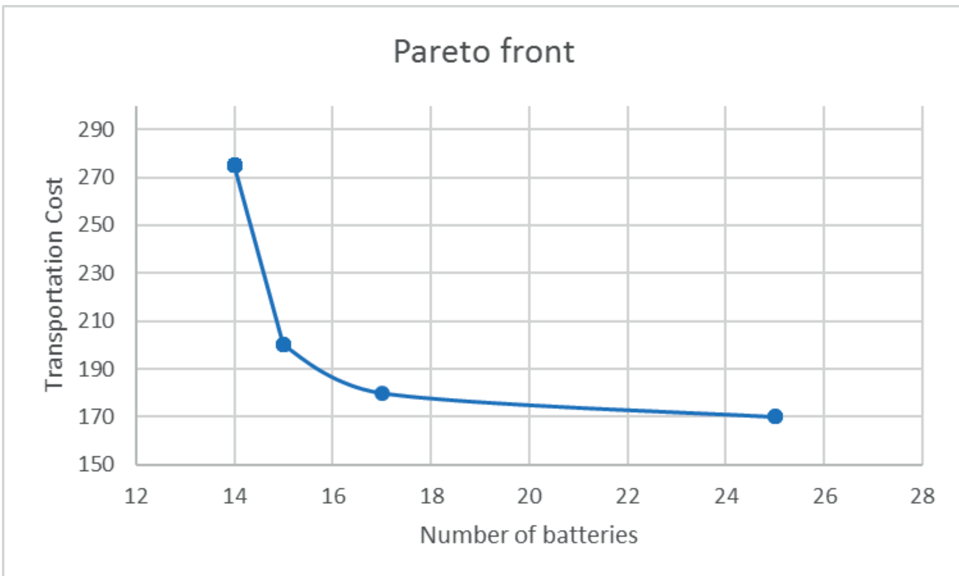

Figure 8. The pareto front for the P30 data set

To illustrate the output of the train assignment heuristic, tables 4-7 are used. Table 4 shows the results of the first part of the chromosome of one of the points on the Pareto front. More specifically, it shows the capacity of the batteries installed on the available trains. Table 5 shows the assignment of the load nodes to the generators for the same point on the Pareto front. Table 6 shows the route of each train from the generator to the load nodes and the actual number of trains needed to satisfy the demand. Table 7 shows the charging and discharging schedule for train 1.

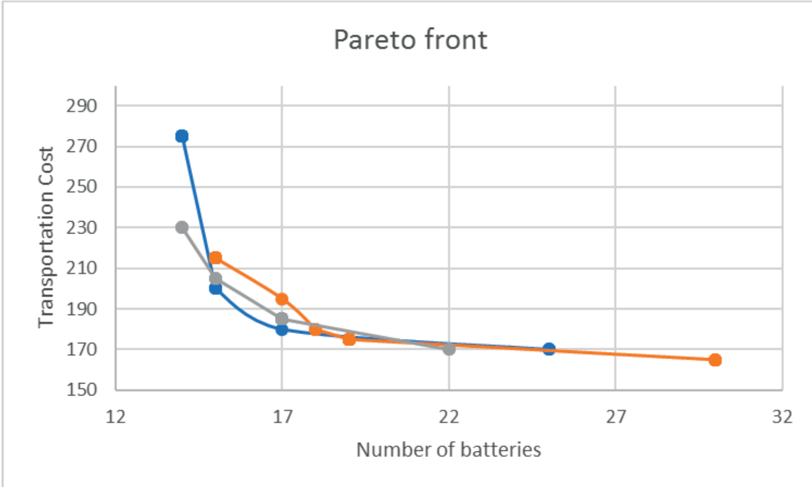

Figure 9. The Pareto Front for Three Runs of The P30 Data Set

Table 4. Solution of One Point On The Pareto Front With Minimum Transportation Cost

Capacity of the trains	20	40	60	20	40	40	40	40	60	100

Table 5. Generator Load Assignment

Load node	1	2	3	4	5	6	7	8	9	10	11
Generator	25	26	23	26	30	25	23	30	28	29	24
Load node	12	13	14	15	16	17	18	19	20	21	22
Generator	26	30	29	26	28	23	25	28	26	29	24

Table 6: Generator Load Train Assignment

Generator	Train assignment	Train Route		
23	1	3	7	17
24	2	11	22	
25	3	1	6	18
26	4	2	4	
26	5	12	15	20
28	6	9	16	19
29	7	10	14	21
30	8	5	8	13

Table 7: Charging and Discharging Schedule

Time span	0-4	4-5	5-9	9-12	12-16	16-20	20-24
Battery location	23	23-3	3	3-7	7	7-17	17
status	charging	transportation	discharging	transportation	discharging	transportation	discharging

5.2. Results for P90 data set

The number of nodes in this data set is 90 and the number of available generators is 40. The battery capacity is 50 MWh and the maximum number of batteries rail cars that could be carried by a single train is 8 batteries. The time spam for the generated Schedule is 24 hours. The charging time and discharging time is 4hrs. The Demand at load nodes is given in Table 7 while the capacities of the generators are given in Table 8. The pareto front for the P90 is shown in Figure 8. The number of points in this set is greater than the P30 as solution space is much bigger.

Table 8: The Demand at Load Nodes

node	Demand	node	demand	node	demand	node	demand	node	demand
1	55	**11**	96	**21**	19	**31**	37	**41**	17
2	22	**12**	27	**22**	26	**32**	37	**42**	18
3	42	**13**	12	**23**	46	**33**	18	**43**	23
4	32	**14**	64	**24**	63	**34**	16	**44**	113
5	56	**15**	48	**25**	25	**35**	53	**45**	63
6	21	**16**	20	**26**	63	**36**	28	**46**	84
7	75	**17**	15	**27**	36	**37**	34	**47**	12
8	50	**18**	11	**28**	33	**38**	20	**48**	12
9	37	**19**	8	**29**	27	**39**	87	**49**	277
10	15	**20**	66	**30**	20	**40**	17	**50**	78

Table 9: Generator Nodes Capacity

Node	capacity	Node	capacity	node	capacity	node	capacity
51	50	**61**	50	**71**	350	**81**	500
52	50	**62**	300	**72**	50	**82**	550
53	300	**63**	350	**73**	50	**83**	50
54	350	**64**	300	**74**	100	**84**	50
55	50	**65**	50	**75**	50	**85**	100
56	50	**66**	100	**76**	100	**86**	300
57	100	**67**	50	**77**	50	**87**	100
58	50	**68**	50	**78**	50	**88**	50
59	100	**69**	50	**79**	50	**89**	50
60	350	**70**	300	**80**	50	**90**	100

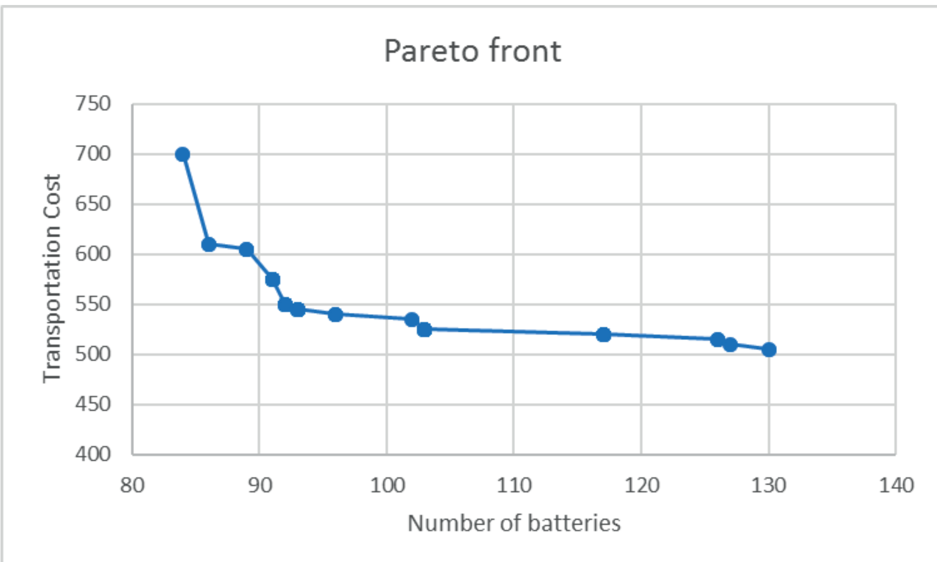

Figure 10: The Pareto Front for the 90-Node Data Set

6. Conclusion

This paper considers the use of railway network to transport the Battery Energy storage system from the generators to areas with high demand or areas that are not linked with transmission lines. The objective is to minimize the total transportation cost and the number of battery vehicle required. After defining the problem as a constrained multi-objective optimization problem, multi-objective genetic algorithm was used to solve it. Two data sets were generated to test the developed GA (P30 and P90 data set). The results show the effectiveness of the proposed algorithm and its ability to converge and to provide good solutions for the problem for small and large instances. The Battery Energy storage system provides a good solution to transport the energy from renewable energy sources to areas with high demand. Future work can include extending this model by including passengers train schedules. With recent environmentally friendly and renewable power generation projects in Egypt, real application of the model on the Egyptian power distribution system can be considered.

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Application of Group Control Charts for Multiple Parts Manufacturing

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Abstract

In many manufacturing processes, multiple identical parts are made in parallel during a single run. Different inspectors may inspect similar parts, and several assembly lines may produce similar products. These scenarios involve multiple stream processes, where a different set of control charts is traditionally required to monitor the performance of each stream over time. As the number of streams increases, applications become unrealistic. Group control charts offer a more viable alternative. This paper presents a review of group charting techniques and highlights recent developments. The paper presents a case study to demonstrate the steps to be followed in selecting among alternative charting techniques. It is hoped that this work guides future applications and encourages quality professionals to select charts better suited to their needs.

1. Introduction

A multiple stream process (MSP) is a process that produces several streams of the output in parallel. Examples of these processes include machines with multiple spindles, injection molds with multiple cavities, turret presses with multiple dies, and filling machines with multiple heads. In some scenarios, multiple identical machines are used on the same production line to help meet flow demand. Similarly, more than one operator or inspector may be needed to speed up assembly or inspection operations. Indeed, the economic gains associated with the increased throughput and productivity of such scenarios is a decisive factor. However, from a statistical point of view, differences between streams and within each stream are inevitable. These differences contribute to the total variability in the output units and determine product quality. Automatic process control, if found economically and technically feasible, represents an excellent approach for keeping the overall variability within acceptable limits. Otherwise, managers are left with two options: to apply no control and hope for the best, or to try to inspect quality into products using 100% inspection.

Considering these same options, Shewhart (1931) proposed the use of control charts for the economic control of quality during production. In his pioneering work, laying the groundwork for statistical process control (SPC) techniques, he was focused on scenarios involving mass production of discreet parts. His simple charting techniques demonstrated an outstanding ability to monitor process performance based on periodic samples of the output. With sample values plotted against statistical limits, operators were able to manage variability during production.

With changes in the market and business models, specialized mass production systems are no longer the dominant environment. Batch production and job shop systems are gaining popularity due to their ability to respond to changes in markets and customer demands. Such a trend is more likely to continue with the ever-increasing need for customized products. Nevertheless, parallel processing of identical units in small batches presents a challenge for traditional SPC. Group control charts (GCCs) appear to offer a viable alternative for controlling process variability. The following section presents a review of the literature on GCCs. The review is aimed at comparing the various charting techniques and identifying guidelines for their applications. This is followed by a case study detailing the steps for application in a local manufacturing company. Concluding remarks with directions for future research are presented in the last section.

2. Literature Review

Group control charts present statistical monitoring techniques for MSPs as described by Boyd (1950), Burr (1976), Nelson (1986), and Mortell & Runger (1995). Sealy (1943) pointed out that the chief motivation for using GCCs was to avoid the high number of charts that would be required when each stream was controlled with a separate pair of charts. He proposed constructing control limits based on the product specification limits. The basic idea was to build only one pair of charts with information from all the streams.

Boyd (1950) considered the case of a vertical boring machine that used multiple spindles to manufacture engine blocks. He noted that the performance of the spindles was "largely independent of each other with respect to their effect on cylinder bore diameter." Therefore, the diameters represented the outcomes of a number of independent sub-processes (i.e., spindles). He suggested that the control limits used for the ordinary X-bar and R charts were appropriate control limits for his group X-bar and R charts. He presented a sample application of the group X-bar and R charts for monitoring the process.

Several researchers expressed concern over the statistical performance of GCCs. Some recommended an adjustment to the control limits so that the false-alarm probability does not exceed the acceptable level. Nelson (1986) proposed run test for GCCs to increase their ability to detect a shift in a single stream. He recommended that the test be utilized in addition to rule 1 of one point beyond the + 3 sigma limits. He suggested that the process should be investigated whenever a sequence of p points on the chart are associated with one stream. He provided values of p for the different number of streams and false alarm rates.

Mortell and Runger (1995) pointed out that Nelson's run tests are likely to increase the overall false alarm rate. They argued that the tradeoff between the probability of false alarms and chart sensitivity does not correspond to the number of streams. Therefore, either the false-alarm rate will be too high or the sensitivity to detect a shift will be too low. Mortell and Runger (1995) proposed monitoring the MSP using two charts: one for monitoring the average across all streams, and another to monitor the range of the steam's means. They compared the performance of these charts with Nelson's runs test using simulated data and reported that the proposed charts are better than the GCC, especially when the variation in the process mean is greater than that between streams. Whereas, Wise and Fair (1998) proposed using the GCC with Nelson's run tests without control limits.

Colbeck (1999) questioned the appropriateness of using 3-sigma limits on a GCC. He proposed two methods for calculating these limits. The first method is based on the distribution of the maximum and minimum values in a sample selected from the process. The second method uses correction factors to widen the control limits. Grimshaw et al. (1999) proposed an adjustment procedure and provided a table of constants to help calculate the control limits. He pointed out that when monitoring a multiple stream process, it is helpful to make a distinction between assignable causes that trigger changes across all the streams and changes that affect one stream only.

Epprecht, Barbosa, and Simoes (2011) proposed modified GCCs for residuals as an alternative scheme for monitoring MSP. This scheme makes a distinction between assignable causes affecting all the streams and those affecting a single stream. If differences between the averages are significant, residuals are obtained based on the average of each stream. Otherwise, a grand average is calculated and used to obtain the residuals from all streams. Operation of the residual chart is similar to that of Boyd's (1950). The difference is in the way the control limits are calculated. The control limit coefficient depends on the number of streams in the process. According to Epprecht et al., (2011), residual GCCs are faster and more efficient at detecting shifts in the mean of one stream. The gain in its performance, compared with other methods, increases with a surge in the number of streams in the process. Epprecht (2015) provided a comprehensive survey of the research motivated by Boyd's original work through 2013.

Despite the increased interest in the performance characteristics of the aforementioned charts, limited research addressed selection and implementation issues. To the best of our knowledge, Jirasettapong and Rojanarowan (2011) appear to have authored the only publication addressing this topic. They provided a taxonomy, in the form of a tree diagram, to classify the MSPs according to the number of streams, the degree of correlation among streams, the feasibility of using one chart per stream, and the ability to center each on target. These factors are addressed in the case study following the procedures outlined in Figure 1.

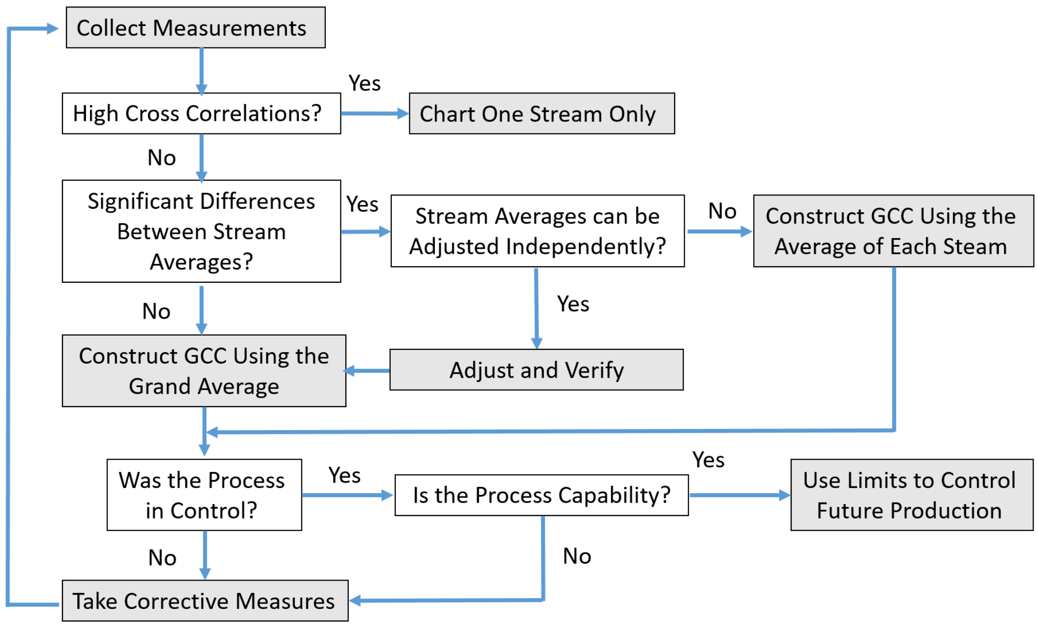

Figure 1. Procedure for selecting SPC charting technique

3. Case Study

This case study involves the application of SPC at a local manufacturing company located in Wichita, Kansas. At the request of the production manager, the company is referred to as AE. The company offers full-service from production parts to mechanical assemblies for the aerospace industry. AE was established in 2004, and is currently AS9100 (Rev C) certified. The company makes every effort to pursue the highest quality levels and exceed expectations.

One of the repeated orders requires processing the part shown in Figure 2. Key characteristics of the part include the diameter of hole number 9 as shown in Figure 2. Parts are machined from a special aluminum alloy in small batches of 200 parts each. Orders are repeated eight times a year. Parts are manufactured using a horizontal 4-Axis machining center (Makino a51nx). The process utilizes a special fixture to allow for machining five parts per setup. As parts are manufactured in different positions on the fixture, the process is classified as a MSP. Upon completion of each run, diameters are measured using a three-point bore gage (Mitutoyo Digital Holtest Bore Micrometer 468-234). AE would like to implement SPC to monitor production during each run to ensure acceptable quality. However, the option of setting up ten different charts for this key characteristic is not feasible. Management feels that the time spent entering the measurements on such a large number of charts would decrease productivity and also discourage operators from using the charts.

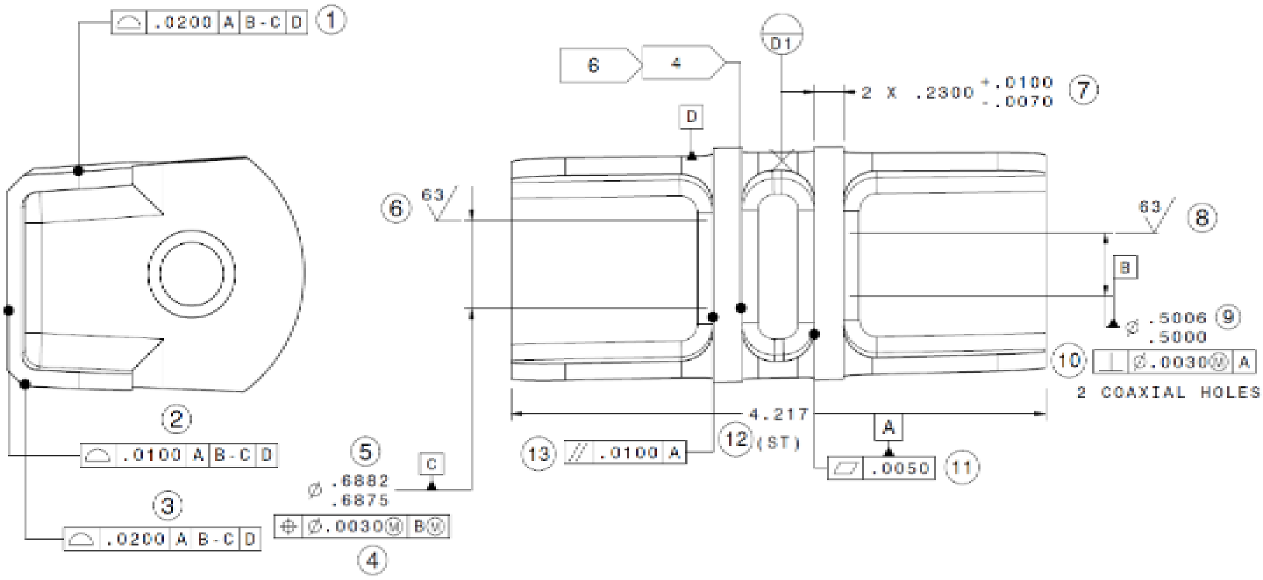

Figure 2. Part drawing with specifications

In this case study, we present the procedures followed in setting up a GCC for monitoring the diameter of hole number 9. The production manager will follow the same procedure in setting up charts for monitoring other key characteristics on this part. The study started with an evaluation of the gage capability as described by Wheeler (2008). The results classified the gage as a third-class monitor (30%-55% of total variability). It was recommended that AE consider alternative gages to allow for future improvements.

Upon the release of a production order, samples of three runs were obtained each day for six days. The inspector was instructed to record both the diameter measurement and the part position on the fixture by utilizing the tray shown in Figure 3. The measurements of the sample is shown in Table 1.

Figure 3. Special tray used to record the measurement and position on fixture

The first step was examining the cross-correlation between positions. If the level of correlation among the different positions is very high, a single chart for one stream could be used to represent the status of all the others (Montgomery, 2013). In this case, the Pearson product moment correlations for each pair of positions was calculated. Values of the coefficient (*r*) ranging from -1 to +1 for each pair of positions were obtained as shown in Table 2. It is concluded that only two positions (POS 3 and POS 4) appear to have a moderate level of association. This indicated that one position could not represent all the other positions. As such, the option of charting measurements from only one position as representative of the others was excluded. As noted in Section 2, Boyd's GCCs will work if the values of the quality variables in the different positions are independent and identically distributed.

Differences between position averages were analyzed using a one-way Analysis of Variance (ANOVA). The results shown in Table 3 indicated no significant differences with a p-value of 0.12. This suggested that a grand average of 0.5002" could be used in calculating the residuals of all (18X5) 90 measurements. The maximum and the minimum values from each sample were used to calculate the ranges. This resulted in an average range of 0.00035" with an upper control limit (based on 5 streams) of 0.000901". Positions associated with the highest range from each sample were also noted and indicated on the chart. As shown in Figure 4, all ranges appear within limits with none of the positions providing the highest range five times in succession (Nelson 1986).

Table 1. Sample of process data

Sample	POS	Observation			X-bar	R
1	POS 1	0.5001	0.5000	0.4995	0.49987	0.00060
	POS 2	0.5001	0.5001	0.5001	0.50010	0.00000
	POS 3	0.5001	0.5002	0.4998	0.50003	0.00040
	POS 4	0.4999	0.5002	0.5000	0.50003	0.00030
	POS 5	0.5001	0.5002	0.5002	0.50017	0.00010
2	POS 1	0.5001	0.4993	0.5002	0.49993	0.00090
	POS 2	0.5000	0.4997	0.4999	0.49987	0.00030
	POS 3	0.4997	0.5002	0.5002	0.50003	0.00050
	POS 4	0.4996	0.5002	0.5002	0.50000	0.00060
	POS 5	0.4998	0.4999	0.5002	0.49997	0.00040
3	POS 1	0.4999	0.4998	0.5001	0.49993	0.00030
	POS 2	0.4999	0.5000	0.5001	0.50000	0.00020

	POS 3	0.4998	0.5003	0.4997	0.49993	0.00060
	POS 4	0.5001	0.5002	0.4996	0.49997	0.00060
	POS 5	0.5000	0.5002	0.5000	0.50007	0.00020
. .	. .	. .	. .	. .	. .	. .

Table 2. Cross correlation between positions

Variable	POS 1	POS 2	POS 3	POS 4	POS 5
POS 1	1.00000	0.24633	0.06026	-0.19583	0.09971
POS 2	0.24633	1.00000	-0.04040	0.02786	0.26373
POS 3	0.06026	-0.04040	1.00000	0.52913	0.33377
POS 4	-0.19583	0.02786	0.52913	1.00000	0.25629
POS 5	0.09971	0.26373	0.33377	0.25629	1.00000

Table 3. ANOVA for differences between position averages

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between positions	2.87E-07	4	7.18E-08	1.86	0.1254
Within positions	3.28444E-06	85	3.86E-08		
Total	3.57156E-06	89			

Consequently, the maximum and minimum values of the residuals from each sample were analyzed using the residuals group chart. According to Epprecht et al., (2011) the operation of the chart is identical to that of Boyd's GCC for the averages. The difference is in selecting the value of the control limit coefficient (K). A value of K = 3.129 was used to keep the overall false-alarm rate within 370 points on average. This is the rate typically reported for the traditional Shewhart type charts with three sigma limits. Based on an average range of 0.00035, trial limits were established at ± 0.000421. Both the maximum and minimum values of the average residual for each sample were plotted on the chart in Figure 5 with their associated positions.

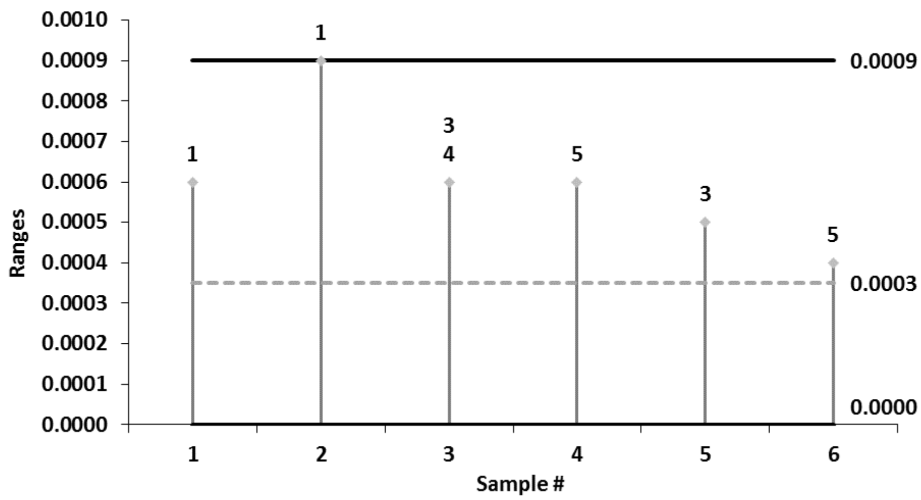

Figure 4. R Chart – Residual's Group Control Chart

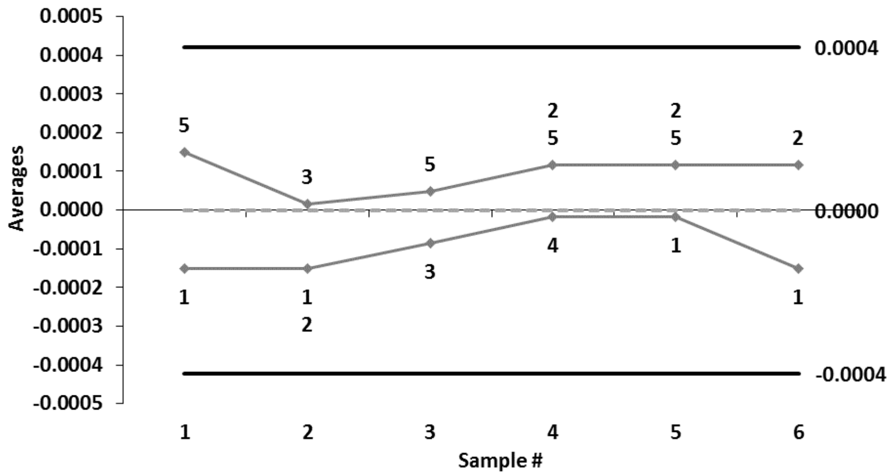

Figure 5. X-Bar Chart – Residual's Group Control Chart

All averages are within the limits with none of the positions giving the highest or lowest value five times in succession as shown in Figure 5. The limits on both charts in Figures 4 and 5 could be extended to monitor future production with some training for operators on the use of residual GCCs. Process standard deviation indicate the need for managerial action to reduce variability. One of the options currently considered is the acquisition of new measurement equipment with significantly lower contribution to the total process variability.

4. Conclusions

This paper presented a review of the statistical procedures that have been developed and implemented for monitoring multiple stream processes. Given the current state of technology, many companies are utilizing methods, which allow for simultaneous processing of multiple units. The nature of such processes challenges the basic assumptions of the traditional SPC techniques. GCCs are gaining popularity in the job shop environment, food and pharmaceutical industries, data processing centers as well as multiple assembly and/or inspection lines. This review of statistical procedures identified less than adequate number of guidelines allowing for effective implementation of GCC as a viable alternative for traditional SPC. It is worth noting that most SPC training programs exclude GCCs. It is evident that few practitioners received appropriate training on the design and use of these charts. Even comprehensive Six-sigma training programs do not include the topic. Given the current state of the manufacturing technology and future trends, this could present a serious challenge to the effective implementation of SPC techniques. A good place to start would be to include GCCs as part of any statistical quality control course offered to students at the junior or senior level.

The case study in this paper offers an application based on real-life data. It introduces GCCs as a viable alternative for traditional SPC with significant reduction in the number of charts used. As judged by AE production manager, residual group control charts are relatively easy to implement and resulted in a renewed commitment to improvement. In addition, there is absence of software functions that can support the construction of various GCCs. These authors were required to develop special programs in Microsoft Excel to support their application. Readers interested in additional information may contact the authors for copies of these programs. It is hoped that this work will encourage quality professionals to implement charts better suited to their needs following similar procedures. With the ever-increasing demand for small lot sizes, limits on the average run length need to be more realistic. There is a need for continuing research on the design and operation of GCCs and action rules to increase their ability to detect out-of-control performance. These authors are currently studying appropriate designs of GCCs in a job shop environment.

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Effects of Design Parameters on Dimensional Accuracy of Parts Made on a Mini 3-Axis CNC Router

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Abstract

Computer numerical control (CNC) is a very broad term that encompasses a variety of types of machines used in industrial automation — all with different sizes, shapes, and functions. But the easiest way to think about CNC is to simply understand that it is all about using a computer as a means to control a machine that carves useful objects from solid blocks of material. Traditional CNC machines are expensive, complicated, and typically only found in large manufacturing companies that can afford them. Small hobbyist CNC machines can run anywhere from $7,000 and higher; professional machines can cost millions of dollars! Now, for a fraction of the cost — under $800 one can own a Mini 3-axis CNC machine and cut, drill, mill, and carve objects of one's imagination. In this paper, a Mini 3-axis CNC router was assembled and tested for machining different materials such as plastic and wood. Simple shapes of circles (diameter, d = 1") and squares (side, a = 1") were cut using the CNC router. G-Code programs were developed to cut the required circles and squares. A digital caliper was used to measure the diameter of the circles and the side of the squares. Data were collected for a 2^k factorial design experiments considering 2-levels for parameters: spindle speed, feed rate, cut depth, object shape, and material. Statistical analyses were performed to determine the effects of chosen parameters on the dimensional accuracy of the parts made. The results indicated that the parameters material, object shape, and cut depth have significant effects on the dimensional accuracy of the parts made.

1. Introduction

Numerical control, popularly known as NC is very commonly used in the machine tools. Numerical control is defined as the form of programmable automation, in which the process is controlled by the numbers, letters, and symbols. In case of the machine tools this programmable automation is used for the operation of the machines. CNC is the short form for Computer Numerical Control. The NC machine works as per the program of instructions fed into the controller unit of the machine. The CNC machine comprises of a mini computer or a microcomputer that acts as the controller unit of the machine. While in the NC machine the program is fed into the punch cards, in CNC machines the program of instructions is fed directly into the computer via a small board similar to the traditional keyboard. CNC machines were originally built for machining metals. They were subsequently adapted for other industries such as wood, fabric, foam, and plastic to name just a few. All these machines have some features in common which are: a program (instructions), a controller, and a machine tool (Groover, 2015).

CNC router is a computer-controlled cutting machine related to the hand held router used for cutting various hard materials, such as wood, composites, aluminum, steel, plastics, and foams. CNC routers can perform the tasks of many carpentry shop machines such as the panel saw, the spindle molder, and the boring machine. A CNC router is very similar in concept to a CNC milling machine. Instead of routing by hand, tool paths are controlled via computer numerical control. The CNC router is one of many kinds of tools that have CNC variants.

A CNC router typically produces consistent and high-quality work and improves factory productivity. Automation and precision are the key benefits of CNC router tables. A CNC router can reduce waste, frequency of errors, and the time the finished product takes to get to market (Albert, 2017).

This paper is one of the outcomes of the Mercer Summer Engineering Experience (MeSEE 2017), an Academic Training program, in which multidisciplinary student teams were trained in engineering labs and then worked on hand-on projects over a period of 10 weeks (30-40 hours/ week) in the lab environment, during 2017 Summer semester to complete the chosen projects. Three senior students (Abdullah Alfadel, Industrial Engineering; Kyle Trammell, Mechanical Engineering; and Riley Atkinson, Industrial Management) forming a multidisciplinary team worked on this project. The overall objective of this project is to assemble/build and test a mini 3-axis CNC router in a laboratory environment; and conduct experiments, collect, analyze, and interpret data within the ten weeks duration of the academic training.

In this project, the student team has built and tested a DIY CNC router for machining different materials, plastic and wood. Simple shapes of circles (diameter, d = 1") and squares (side, a = 1") were cut using the CNC router. G-Code programs were developed to cut the required circles and squares. A digital caliper was used to measure the diameter of the circles and the side of the squares. The measured data were used to perform statistical analyses using Minitab and/or Microsoft Excel. Results obtained from statistical analyses were presented and discussed.

2. Background/Literature review

2.1. CNC history

NC or simply Numerical Control was developed in the late 1940s and early 1950s by John T. Parsons in collaboration with MIT (Massachusetts Institute of Technology). It was developed to help in the post war manufacturing effort. Aircraft parts were becoming more complex and required a level of precision that human operators could not achieve. At first, machines were hardwired and then instructions were given via punched tape starting in 1952. Five years later, NC machines were being installed in metal working production environments all over the United States. By the mid 1960s, NC technology was playing a dominant role in the industry. Most machine programs were recorded on a punched paper or aluminum tape until about 1980. The growth of microprocessor technology in the 1970s and 1980s made it possible for computers to be connected directly to NC machines using cables and hence the term CNC (Groover, 2015).

There are two main types of CNC machine tools and the control systems used with them differ because of the basic differences in the functions of the machines to be controlled. They are known as point-to-point and contouring controls. Some machine tools for example drilling, boring and tapping machines etc., require the cutter and the work piece to be placed at a certain fixed relative positions at which they must remain while the cutter does its work. These machines are known as point-to-point machines. Other type of machine tools involves motion of work piece with respect to the cutter while cutting operation is taking place. These machine tools include milling, routing machines etc., and are known as contouring machines. A milling machine is a machine that has a spindle (a device similar to a router) with a special tool that spins and cuts in various directions and moves in three different directions along the x, y, and z axes (Hood-Daniel

& Kelly, 2009).

A DIY Desktop CNC Machine is a “personal” version of a CNC machine. It is controlled by a desktop computer and is designed for the hobbyist or enthusiast to create objects within a relatively compact space and at modest expense. To that end, the DIY Desktop CNC Machine is designed to provide a resolution of one thousandth of an inch (0.001”) per step in each axis, and was intended to be accessible and buildable by the average DIY'er with non-specialist domestic tools (DIY CNC Router Kit, 2017; Ginting, Hydiyoso, & Aulia, 2017).

A small CNC router (work area: 20 cm x 20 cm) was installed and tested in a small scale industry in Indonesia for cutting, engraving, and marking on wood, acrylic and PCB objects. When tested, this router was able to provide 98.5% of carving accuracy and 100% of depth accuracy (Ginting, Hydiyoso, & Aulia, 2017). An automatic mini CNC machine for PCB drawing and drilling based on low cost CNC system was designed and made by incorporating features of PC with ATMEGA 328 controller in an arduino board, an open-source electronics platform based on easy-to-use hardware and software (Mudekar et al, 2016).

A low cost CNC router was designed and fabricated to fulfill the demand of CNC routers in small scale to large scale industries with optimized low cost (Jayachandraiah et al, 2014). A mini CNC router which is compatible to extrude as 3D printer, less expensive and affordable, compact in size and less power consuming, with user friendly interface to operate very smoothly, was designed and fabricated (Dey, Mondal, & Barik, 2016).

Effect of machining parameters such as speed, feed, and depth of cut on surface finish on a CNC router were analyzed using Taguchi's robust design approach using orthogonal arrays and analysis of variance models. The results indicated that feed rate has the highest influence on surface finish followed by spindle speed and depth of cut (Patel & Patni, 2014).

3. Materials and methods

3.1. DIY CNC machine

DIY CNC Router Kit used in this project is a mini CNC for study and research. It requires self-assembling and certain mechanical skills to assemble. According to the product details "The machine can carve wood, plastic, acrylic, PCB CCL, soft metals like copper and aluminum and other materials: working area: 240 * 170 * 65 mm; positioning accuracy: 0.04 mm; and software: easy to use GRBL" (DIY CNC Router Kit, 2017). Figure 1 shows the components of the DIY CNC Router Kit.

3.2. Measuring device

In this project, a digital caliper was used to measure the diameter of the circles and the side of the squares (Fig. 2). A caliper is a device used to measure the distance between two opposite sides of an object. It has a rated accuracy of 0.001 inches (Digital Calipers, 2017).

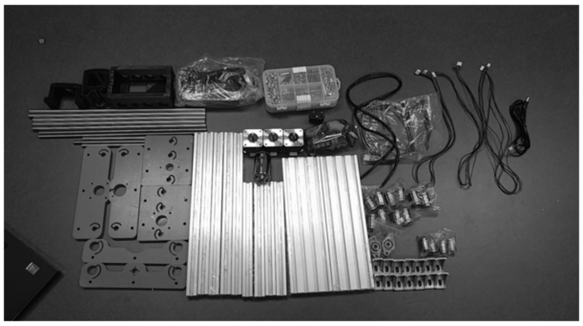


Figure 1. Components of DIY CNC router kit

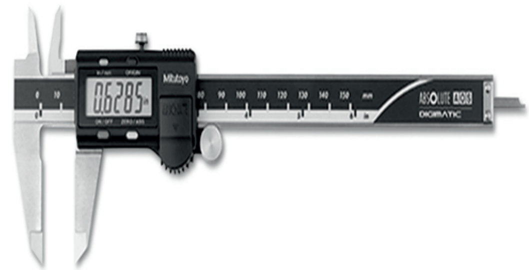


Figure 2. Digital caliper

3.3. G-codes for cutting circles and squares (Nanfara, Uccello, & Murphy, 1999)

The G-codes for cutting circles and squares are given in Table 1.

Table 1. G-codes for circles and squares

Circle	Square
G20 M3 S1000 G90 G00 X0 Y0 Z0 G01 Z-___ F__ G02 X0 Y0 I.446 J0 F__ G00 X0 Y0 G01 Z-___ F__ G02 X0 Y0 I.446 J0 F__ M30 G28	G20 G90 G40 G0 M3 S____ Z-_____ G1 X.918 F__ G1 Y.918 G1 X0 G1 Y0 M30 G28

Two levels of spindle speed (S), feed rate (F), and cut depth (Z) were used to cut two simple shapes, circles and squares, on two different materials, plastic and wood.

3.4. The electronics of the CNC

Each CNC machine requires an electronic unit (Figure 3) to run the codes, move the shafts and the platform. It depends on the type of the CNC if it is 5 axes or 3 axes and also if there is a need to use coolant to cut aluminum parts. This DIY CNC requires an electronic unit to machine parts (DIY CNC Router Kit, 2017):

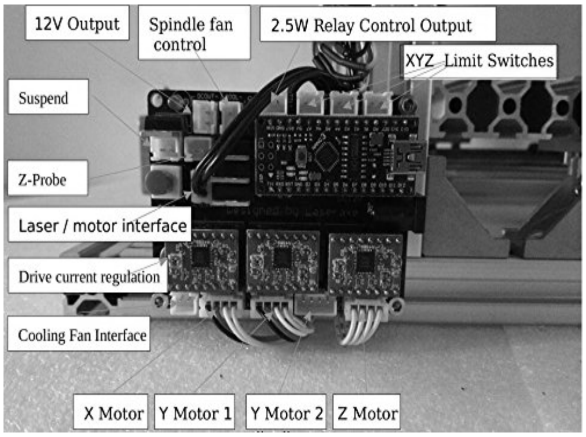


Figure 3. The electronics of the CNC router

- **Partmore:** 3 Axis CNC Controller Board (Fig. 3)
- **Compatible motor:** 2 Phase 4 Wire Stepper Motor
- **Working voltage:** DC 12V
- **Board size:** 100 x 80 mm (L*W)
- 3 **Stepper motor drivers**: A4988
- **Spindle drive chip**: MOSFET, the highest 60V
- **Support stepper motor:** 12V, maximum current of 2A or less is recommended within 1.5A and additional heat
- **Master chip**: Atmel 328P (Arduino Nano compatible)
- **Software**: GRBL controller, Universal G-code sender
- **Stepper motor specification:** Fuselage length 34mm; Current 1.33A, 12V; Torque 0.25N/m; and 4 lines

The assembled CNC router is shown in Figure 4.

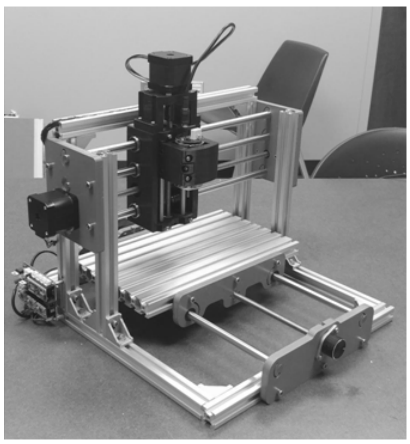


Figure 4. Assembled CNC router

3.5. Factors and Levels

To determine the accuracy with which the CNC router can cut parts, 25 factorial design experiments were designed with two levels for each factor under consideration (Montgomery, 2017): Speed: 800 and 1000 rpm; Feed Rate: 8 and 10 inches/min; Cut Depth: 0.08 and 0.1 inch; Material: Plastic and Wood; and Shape: Circle (d = 1±0.02") and Square (a = 1±0.02").

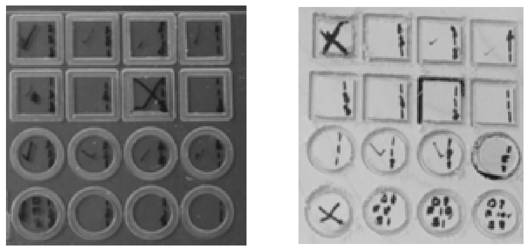
Experiments were conducted with two replicates. The data collected are shown in Table 2. All measurements were found to be within the tolerance limits 1±0.02" indicating that the CNC router is capable of cutting plastic and wood within the dimensional tolerance.

Table 2. Data collected

StdOrder	Speed	Feed Rate	Cut Depth	Materials	Shape	R1	R2
1	800	8	0.08	Plastic	Circle	1.011	1.006
2	800	8	0.08	Plastic	Square	1.02	1.015
3	800	8	0.08	Wood	Circle	1.008	1
4	800	8	0.08	Wood	Square	1.007	1.012
5	800	8	0.1	Plastic	Circle	1.014	1.011
6	800	8	0.1	Plastic	Square	1.002	1
7	800	8	0.1	Wood	Circle	1.007	1
8	800	8	0.1	Wood	Square	1.006	1.004
9	800	10	0.08	Plastic	Circle	1.005	1.01
10	800	10	0.08	Plastic	Square	1.015	1.012
11	800	10	0.08	Wood	Circle	1.009	1.001
12	800	10	0.08	Wood	Square	1.011	1.006
13	800	10	0.1	Plastic	Circle	1.015	1.015
14	800	10	0.1	Plastic	Square	1.005	1.01
15	800	10	0.1	Wood	Circle	1.005	1
16	800	10	0.1	Wood	Square	1.001	1.003
17	1000	8	0.08	Plastic	Circle	1.008	1.005
18	1000	8	0.08	Plastic	Square	1.019	1.018
19	1000	8	0.08	Wood	Circle	1.003	0.996
20	1000	8	0.08	Wood	Square	1.008	1.004
21	1000	8	0.1	Plastic	Circle	1.01	1.01
22	1000	8	0.1	Plastic	Square	1.007	1.002
23	1000	8	0.1	Wood	Circle	1.014	1.007
24	1000	8	0.1	Wood	Square	1.006	1.006
25	1000	10	0.08	Plastic	Circle	1.011	1.008
26	1000	10	0.08	Plastic	Square	1.015	1.013
27	1000	10	0.08	Wood	Circle	0.996	0.992
28	1000	10	0.08	Wood	Square	1.01	1.01
29	1000	10	0.1	Plastic	Circle	1.01	1.013
30	1000	10	0.1	Plastic	Square	1.006	1.005
31	1000	10	0.1	Wood	Circle	1.006	1.002
32	1000	10	0.1	Wood	Square	1.003	1.002

4. Results and discussions

Samples of square and circular parts (plastic and wood) were cut using the CNC router. They are shown in Figure 5. A completely randomized 25 full factorial designs were used to collect data (Montgomery, 2017). Minitab 17 software was used to analyze the data (Minitab 17, 2017). Table 3 shows the Minitab output of Analysis of Variance (ANOVA).



(a) (b)

Figure 5. Samples of square and circular parts made: (a) Plastic and (b) Wood

Table 3. Minitab output - ANOVA table

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Significant?**
Model	31	0.001735	0.000056	6.10	0.000	
Linear	5	0.000624	0.000125	13.60	0.000	
Speed	1	0.000007	0.000007	0.75	0.393	
Feed Rate	1	0.000007	0.000007	0.75	0.393	
Cut Depth	**1**	**0.000051**	**0.000051**	**5.53**	**0.025**	**S**
Material	**1**	**0.000512**	**0.000512**	**55.81**	**0.000**	**S**
Shape	**1**	**0.000047**	**0.000047**	**5.15**	**0.030**	**S**
2-Way Interactions	10	0.000775	0.000077	8.45	0.000	
Speed*Feed Rate	1	0.000007	0.000007	0.75	0.393	
Speed*Cut Depth	1	0.000029	0.000029	3.15	0.085	
Speed*Material	1	0.000001	0.000001	0.14	0.713	
Speed*shape	1	0.000015	0.000015	1.64	0.210	
Feed Rate*Cut Depth	1	0.000002	0.000002	0.21	0.653	
Feed Rate*Material	1	0.000026	0.000026	2.86	0.100	
Feed Rate*Shape	1	0.000000	0.000000	0.02	0.902	
Cut Depth*Material	**1**	**0.000047**	**0.000047**	**5.15**	**0.030**	**S**
Cut Depth*Shape	**1**	**0.000606**	**0.000606**	**66.11**	**0.000**	**S**
Material*Shape	**1**	**0.000041**	**0.000041**	**4.43**	**0.043**	**S**
3-Way Interactions	10	0.000219	0.000022	2.39	0.030	
Speed*Feed Rate*Cut Depth	1	0.000013	0.000013	1.43	0.240	
Speed*Feed Rate*Material	1	0.000001	0.000001	0.14	0.713	
Speed*Feed Rate*Shape	1	0.000004	0.000004	0.38	0.540	
Speed*Cut Depth*Material	**1**	**0.000070**	**0.000070**	**7.65**	**0.009**	**S**
Speed*Cut Depth*Shape	1	0.000013	0.000013	1.43	0.240	
Speed*Material*Shape	1	0.000000	0.000000	0.04	0.838	
Feed Rate*Cut Depth*Material	**1**	**0.000058**	**0.000058**	**6.34**	**0.017**	**S**
Feed Rate*Cut Depth*Shape	1	0.000004	0.000004	0.38	0.540	
Feed Rate*Material*Shape	1	0.000015	0.000015	1.64	0.210	
Cut Depth*Material*Shape	**1**	**0.000041**	**0.000041**	**4.43**	**0.043**	**S**
4-Way Interactions	5	0.000115	0.000023	2.51	0.050	
Speed*Feed Rate*Cut Depth*Material	1	0.000002	0.000002	0.21	0.653	
Speed*Feed Rate*Cut Depth*Shape	1	0.000003	0.000003	0.29	0.595	
Speed*Feed Rate*Material*Shape	**1**	**0.000041**	**0.000041**	**4.43**	**0.043**	**S**
Speed*Cut Depth*Material*Shape	**1**	**0.000044**	**0.000044**	**4.79**	**0.036**	**S**

Feed Rate*Cut Depth*Material*Shape	1	0.000026	0.000026	2.86	0.100	
5-Way Interactions	1	0.000003	0.000003	0.29	0.595	
Speed*Feed Rate*Cut Depth*Material*Shape	1	0.000003	0.000003	0.29	0.595	
Error	32	0.000293	0.000009			
Total	63	0.002029				

Table 3 indicates that with 5% level of significance and a p-value < 0.05, the following factors are found to be significant (highlighted bold with S after P-Value):

Main effects: Cut Depth, Material, and Shape
2-Factor Interactions: Cut Depth*Material, Cut Depth*Shape, and Material*Shape
3-Factor Interactions: Speed*Cut Depth*Material, Feed Rate*Cut Depth*Material, and Cut Depth*Material*Shape
4-Factor Interactions: Speed*Feed Rate*Material*Shape and Speed*Cut Depth*Material*Shape

Considering main effects and 2-factor interaction effects, it can be concluded that Cut Depth, Material, and Shape have significant effects on the diameter of circles and the side of squares cut using the CNC router. All five factors are found to have influence on the measurements when 3-factor and 4-factor interactions are considered.

The normal probability plot of the residuals, nearly linear, is shown in Figure 6. The fitted values versus residuals plots are shown in Figure 7. Figures 6 and 7 indicate that the residuals are normally distributed and there is nothing unusual about the residuals/errors.

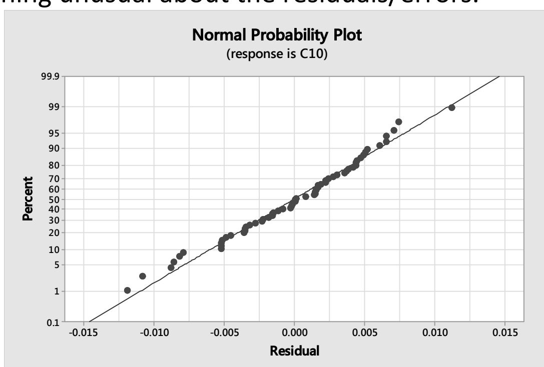


Figure 6. Normal probability plot

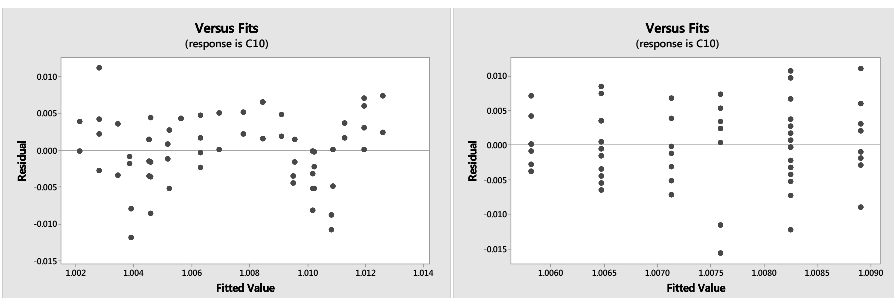


Figure 7. Fitted value versus residual plots

The main effects plots are shown in Figure 8. It is seen from the figure that:

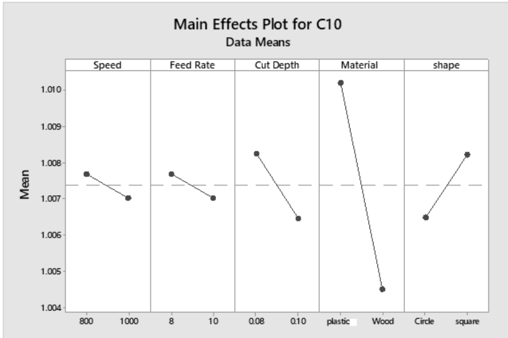


Figure 8. Main effects plot

1. The material factor is found to be the most significant factor;
2. The shape and cut depth factors are the next most significant factors;
3. The speed and feed rate factors have minimum effect.

The results are consistent with the p-values for the above factors in the ANOVA table (Table 3).

5. Conclusions and recommendations

The DIY CNC router assembled and tested by the student team is capable of cutting materials (plastic and wood) within the dimensional tolerances (1±0.02"). The Minitab output shows that the normal probability plot is nearly linear indicating that the residuals/errors are normally distributed and there is nothing unusual about the residuals. Main effects and the 2-factor interaction effects indicate that material, shape, and cut depth have significant effects on the measured values. All five factors showed significant effects at higher order interactions (3-factor and 4-factor interactions). The main effect plots show that the material has the highest effects on the machining, as it was expected because the materials used, plastic and wood, have different levels of softness.

Through this hands-on project, the student team was trained in assembling and testing a CNC router, cutting simple to complex shapes using G-Codes, measuring the parts made for dimensional accuracy, collecting data for experimental design, and analyzing the data using Minitab/Microsoft Excel. This is an excellent hand-on learning experience for the student team. Using the DIY CNC router, other materials such as wax, acrylic, soft metals like copper and aluminum can be cut and tested for dimensional accuracy. The CNC router assembled and tested is now available for other students for further studies.

6. Acknowledgment

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A Benchmark Study- How Industrial Engineering Undergraduate Programs are Addressing Healthcare Needs

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Abstract

While healthcare in the U.S. has made great strides at improvement, the delivery system still needs major changes, as evidenced by increasing costs (4-10% per year) and ongoing problems with patient safety. Healthcare improvement requires skills in quality, information technology, safety, human factors, and project management, which are all topics taught in the Industrial Engineering (IE) curriculum. However, for IE to accurately address healthcare's needs, curricula need to be enhanced with healthcare applications and reinforced with hands-on experience. As the influence of IE in healthcare grows, it is important to assess if academia is keeping up with this change. This study benchmarked IE undergraduate programs in the U.S. to evaluate their emphasis on healthcare, including courses, certificate programs and concentration areas or tracks. In addition, this study reviews an approach taken by the Louisiana State University IE program through a "Partnership to Prepare Undergraduates in Industrial Engineering for Careers in Healthcare" with the W. M. Keck Foundation as an example of integrating healthcare into IE curriculum. Lessons learned from this study are discussed and used to propose guidelines to integrate healthcare topics in IE curricula. Findings from this research will contribute to a better understanding of the availability of IE programs with a healthcare focus and formally develop as an academic path for undergraduate students.

1. Introduction

Healthcare and medical delivery systems are rapidly changing and striving for improvement, however, the road to improvement for healthcare is slow. A few challenges include rising costs of healthcare delivery, increase in patient volumes, and the high risk of chronic disease in an aging population coupled with a shortage of medical professionals and governmental penalties for readmissions and errors that reduces hospital reimbursements (Nambiar, Bhardwaj, Sethi, & Vargheese, 2013). More than half of all healthcare spending is attributed to waste, that is $1.2 trillion of the $2.2 trillion spent by the US annually (PwC, 2008).

Previous studies have shown efforts in utilizing industrial and systems engineering and lean methodology concepts to make improvements in three main areas: data analysis, inefficiencies and waste, and adapting a lean culture(Agarwal, Sands, & Schneider, 2010; Bentley, 2008; Brandao de

Souza, 2009; Gotz & Borland, 2016; Kumar, Ghildayal, & Shah, 2011; Vazquez, 2019). Moldovan (2018) found the most significant lean improvements in healthcare were in standardizing patient care and improving efficiencies and concluded that lean thinking in healthcare could potentially improve process performance, organizational structure and health performance outcomes. The Institute for Healthcare Improvement states that lean thinking in healthcare requires a shift in leadership, culture and processes (IHI, 2005). Additionally, promotion of electronic health record (EHR) systems and digitization efforts combined with the push for more efficient and effective healthcare delivery processes will require data collection and analysis of quality measures (Gotz & Borland, 2016).

Traditional IE course competencies that address these three areas are shown in Figure 1. Even though industrial engineers are taught concepts that can be applied in healthcare, there are still gaps in the widespread use of IE tools. An AHRQ report titled "Industrial and System Engineering and Healthcare: Critical Areas of Research", identified nine barriers and four facilitators to achieving breakthrough change in healthcare delivery. The report emphasized how crucial IE tools can be in addressing the issues of the healthcare industry. However, a noted barrier is the lack of professionals that understand both IE and healthcare (Valdez, Brennan, & Ramly, 2010). Bridging this gap requires tailoring traditional IE curriculum and tools to the unique needs of healthcare.

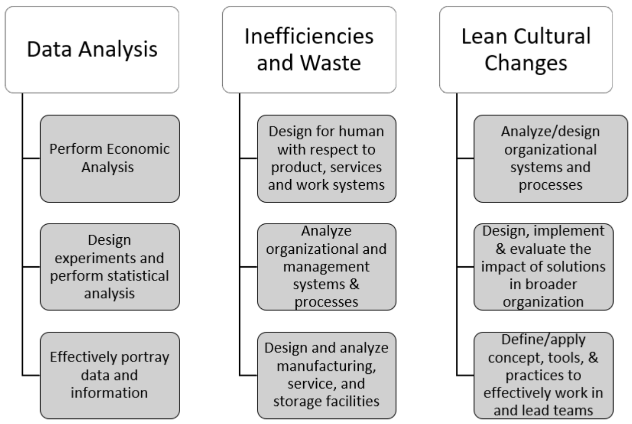

Figure 1: Industrial Engineering Course Competencies related to Healthcare Needs

These gaps are due to the unique differences in healthcare as compared to other industries. For example, metrics are more difficult to operationalize and track due to lack of sufficient IT infrastructure, patient-driven rather than finance-driven project impacts, and teamwork requiring input from multiple disciplines with a single viewpoint (IHI, 2005; Valdez, 2010). It is difficult to drive change in healthcare through the use of data due to lack of transparency with frontline staff. In addition, the lag in healthcare data puts patients at risk for harm to occur before issues are realized.

Traditional IE programs have competencies that meet the needs of healthcare (Figure 1), but there are programs across the US that are specifically designed for the healthcare industry. The purpose of this study is to identify undergraduate IE programs that are taking a step further to bridge the knowledge gap between IE and healthcare.

2. Methodology

The methodology used in this research is of an exploratory nature. The first step in this research was to identify programs being offered in the US specifically for IE in the healthcare industry. For the purpose of this study, the focus was on undergraduate level IE programs across the United States.

The American Society of Engineering Education (ASEE) directory of participating institutes was used to search for institutions in the United States offering an undergraduate degree in Industrial Engineering, Engineering Management, or Systems Engineering in 2018 and whether or not those institutions claimed to have an Area of Emphasis on Industrial Engineering in healthcare (ASEE, 2019). We narrowed down the institutions that met that criteria and reviewed the websites of those programs to find out what is being offered to students to address IE in healthcare, specifically courses, certificate programs, and concentration/emphasis areas.

3. Findings

In total, 91 IE undergraduate programs were found in the ASEE listing out of 279 institutions. Out of the 91 programs, 25 institutions listed healthcare as an area of emphasis (Figure 2). The websites of these institutions were reviewed to find out what type of program was being offered to address Industrial Engineering in healthcare.

Figure 2: Findings Summary of Universities with Programs Related to IE in Healthcare

We found six universities that offered either an emphasis/concentration area, certificate program or course related to healthcare. Each of the six universities had at least one technical elective course related to IE in healthcare. In addition, two universities offered an emphasis/concentration area, two offered a certificate program, and one had both an emphasis/concentration and a certificate program. The certificate programs all included an initiative to provide students with industry experience through senior design projects or internships with local hospitals and agencies. Out of these six universities, three were ranked as Best IE Undergraduate Programs by US News in 2019 (US-News, 2019). The findings are summarized in the Figure 3 below.

College (Undergraduate IE Programs)	Area of Expertise	IE Technical Elective Course	Certificate	Emphasis/ Concentration	Industry Experience
Purdue*	✔	✔		✔	
University of Wisconsin*	✔	✔			
North Carolina State*	✔	✔	✔		✔
University of Pittsburgh	✔	✔	✔	✔	✔
Northern Illinois	✔	✔		✔	
Louisiana State	✔	✔	✔		✔

University					

Figure 3: Summary of Offerings from Universities Across the US (* indicates top 12 university)

Figure 4 provides further detail on the healthcare concentration area offered at each institution:

University of Pittsburgh	Northern Illinois University	Purdue University
• 6 credit hours of required courses • 3 credit hours of approved electives • Senior design project in a healthcare related organization	• A degree plan is available for Health Systems • Choice of electives from list of courses pertaining to healthcare	• Choice of electives from list of courses related to Healthcare, Healthcare Systems, and Simulation and Optimization

Figure 4: Requirements for a Concentration in Healthcare

Figure 5 provides further detail on the certificate program at each institution:

University of Pittsburgh	North Carolina State University	Louisiana State University
• At least 15 credit hours of healthcare related courses • Internship or Co-op within a healthcare organization	• Senior design project in healthcare • Course(s) related to healthcare	• Completion of a Healthcare Engineering Class • Completion of a Seminar Series • Senior design project with a healthcare organization • Internship with a healthcare organization

Figure 5: Requirements for a Certificate in Healthcare

Additionally, information available on the websites about the courses offered at each university were reviewed to get an idea of their content and further explore how these programs addressed the needs in healthcare related to data analysis, inefficiencies and waste and adapting a lean culture. The courses introduced the interconnected sectors in healthcare delivery systems, focused on the management of healthcare services by using IE principles and quantitative decision-making methodologies, and the adaptation of lean and six sigma to rapid and continuous healthcare systems improvement through organizational and process transformation. The courses also looked at the social, regulatory and economic factors unique to healthcare. The contents of these courses tie back to the needs of healthcare (data analysis, inefficiencies and waste, and adapting a lean culture) and show that they are being addressed in a class setting. However, from the information available online, it cannot be determined how effective these courses are in addressing the needs or how in depth the course content is beyond a basic overview.

4. How These Programs Relate Back to the Needs of Healthcare

The courses related to IE in healthcare offered by the six universities provide a basic overview of the industry, which includes the three areas of need in healthcare. A concentration or an emphasis area require students to take a set of courses and may also require them to complete a senior design project. This allows students to get a much better understanding as well as practical experience with the areas of need. Certificate programs require students to complete an internship with a healthcare organization, where students get to understand lean culture and gain practical experience. Figure 6 illustrates the degree to which each program addresses the needs of healthcare:

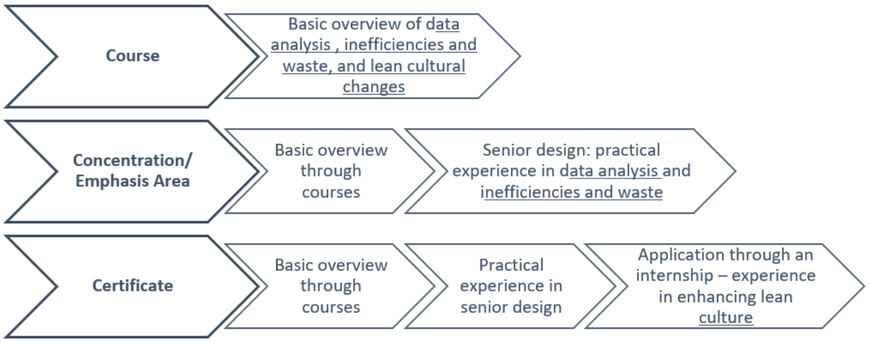

Figure 6: How University Programs Address the needs of Healthcare

5. Case Study: Louisiana State University's Healthcare Certificate Program

The IE department at LSU has partnered with the W.M. Keck Foundation to create a program titled "Partnership to Prepare Industrial Engineering Undergraduates for Careers in Healthcare". It is a certificate program created to bridge the gap between IE curricula and the healthcare industry. The program involves completion of a class in healthcare engineering, a seminar series with healthcare professionals, a senior design project in collaboration with a local healthcare organization, and a healthcare internship.

In 2018, which was the first full year of the partnership program, five students completed their internship with the following local organizations: Our Lady of the Lake Regional Medical Center, Baton Rouge General Medical Center, St. Jude Children's Research Hospital, and East Baton Rouge Parish Emergency Medical Services. Additionally, one student completed their internship with GE Healthcare in Wisconsin. Leaders from the healthcare organizations provided feedback on the performance of the students following the internship and identified areas that they believe require further emphasis to prepare students for careers in healthcare. The five leaders that were surveyed acted as supervisors for the students. This group included one physician, one registered nurse, and three non-clinical healthcare professionals. Their reviews were grouped into the three components, shown in Figure 7.

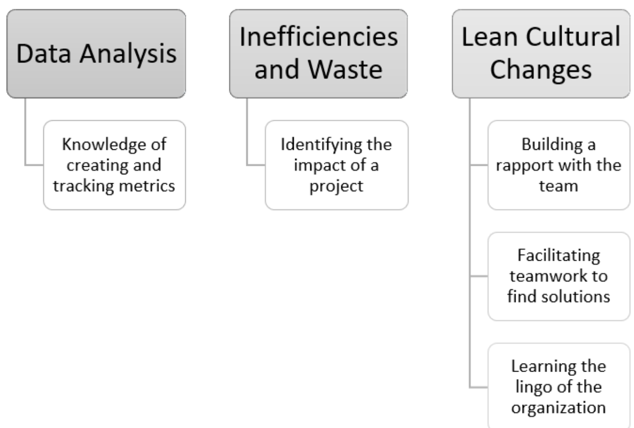

Figure 7: Gaps Identified from Local Healthcare Organizations

From the information gathered in the ASEE search, the gaps identified by the leaders can be addressed by creating programs for healthcare in IE. A course can provide students with knowledge about tracking metrics and identifying the impact of a project. A certificate program or an emphasis area would provide an opportunity for practical experience where students can implement lean into healthcare and start to understand how to work with a team in a healthcare environment.

With the Keck Certificate Program requiring student to complete coursework, a senior design project, and an internship in healthcare, it is successfully addressing the specific needs of healthcare and reinforcing them with real world experience. In turn, the Keck Program is ensuring industry needs noted by healthcare professionals are met.

6. Recommendations

Three percent (3 out of 91) of universities with an undergraduate IE program have an area of concentration/emphasis in healthcare, while another 3% have a certificate program. Eighty percent (19 out of 25) of universities that list healthcare as an area of expertise do not have any courses, emphasis/concentration areas or certificate related to healthcare. Moving forward, the six universities with existing healthcare curricula in IE can network to share best practices and then spread those to other interested IE programs through workshops, conference presentations, webinars, etc. This will benefit IE students looking for expanded career options, IE researchers looking to apply traditional IE methods to healthcare, and the healthcare industry by providing a skilled workforce to address efficiency and cost problems.

In 2017, healthcare spending in the U.S. grew 3.9 percent, reaching $3.5 trillion or $10,739 per person. As a share of the nation's Gross Domestic Product, health spending accounted for 17.9 percent (CMS, 2018). With the healthcare industry being such a substantial part of the economy, it is critical to address its needs. From the results found in the ASEE search, it is evident that there is a lack of undergraduate level IE healthcare programs available. Expanding existing programs and developing new ones will aid in furthering the use of IE principles in healthcare and improve the industry.

For universities attempting to start or expand these programs, the following recommendations are made:

1. Information on healthcare programs in IE needs to be prominent and easily accessible to students.
2. Universities that have faculty that are already conducting research in the area can use their knowledge to support healthcare education in IE.
3. Based on how much emphasis a university wants to achieve, schools can provide courses, concentrations or certificates.
4. IE programs can develop healthcare courses that specifically address the needs pointed out in this research. Current courses address the needs at a very high level and discuss them all in one course. These courses do provide a few ways to adapt traditional IE curriculum to healthcare, but they may not provide enough detail and application to each of the needs.
5. The cultural challenges of adapting lean in healthcare can be tough to introduce in a class, and so a practical experience such as an internship or a senior design project can be a great opportunity to address that need. Consult with local healthcare organizations to create opportunities for practical experience.

7. Conclusion

IE tools and competencies can help address the needs of healthcare. Even though industrial engineers are taught concepts that can be applied in healthcare, there are still gaps in the wide spread use of IE tools because of the lack of professionals that understand both IE and healthcare

(Valdez et al., 2010). Bridging this gap requires tailoring the traditional IE curriculum to the unique needs of healthcare. A benchmark study using a database of universities across the United States showed that only 6 of 91 IE programs have substantial offerings to undergraduates in healthcare-related topics. These universities offer at least one course, concentration/emphasis area, or a certificate program related to IE in healthcare. Based on the findings, it is evident that not enough is being done to tie the IE curriculum to the needs of healthcare. A series of recommendations are made for universities that want to start or expand programs in order to address this gap. There is incredible opportunity for industrial engineers to make an impact in the healthcare industry and the development of these programs can prepare IE undergraduates for a successful and impactful career in healthcare.

8. Acknowledgements

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Does Corporate Social Responsibility Affect Corporate Profit Margins?

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Abstract

Corporate Social Responsibility (CSR) is increasingly playing a major role in Corporate Business Strategy. Initially, many firms played "lip service" to CSR in trying to be compliant with a new initiative that perceived with being counter to the primary responsibility of having a sustainable business and making adequate returns to the shareholders. Today, CSR has had its profile raised in all major corporate firms and is a major topic not only in firm advertising, but also in the media and boardrooms. For example, recent studies are claiming that the Technology sector is in a unique position to assist corporations using their core competencies in data analytics. While many businesses understand that CSR is the "responsible" thing to do, very few have quantified CSR. CSR needs to be investigated and the only way to do so is to conduct studies on the full impact of this important corporate initiative.

This paper analyses the relationship between the major components of CSR and Corporate Financial Performance (CFP). Using a random selection of 100 companies from the Fortune 500, as well as four independent components of CSR, a multiple regression was performed. The four variables were selected from a CSRHub data collection of over 17,000 companies. The final model analyzed the following four independent components of CSR: (1) Community, (2) Employee, (3) Environment, and (4) Governance. The findings show that a linkage exists between firm's profit margin and CSR, with the primary effect coming from the CSR value of employees.

1. Background

Corporate Social Responsibility (CSR) is defined by Investopedia as "A mcorporation's initiatives to assess and take responsibility for the company's effects on environmental and social well-being. The term generally applies to efforts that go beyond what may be required by regulators or environmental protection groups." (Investopedia, 2018). Corporate Financial Performance (CFP) is a firm's Profit Margin as a percentage of Revenue. Such efforts normally come from firms that go beyond being simply "compliant" to EPA and other governmental agencies.

The largest companies in the US are spending in excess of over 15 billion dollars on different components of corporate social responsibility. Despite this massive investment, companies can rarely point at a direct positive link between the money spend on CSR and their financial performance in terms of profitability. This lack of direct cause and effect can often complicate financial prioritization for executives. When allocating company dollars, choices need to be made not just to what a company spends on total CSR, but what they spend against the different components of CSR.

Some might even argue that there is no reason to spend against CSR, in fact, Nobel Prize-winning economist, Milton Friedman, is famously quoted as saying "THERE is one and only one social responsibility of business, to use its resources and engage in activities designed to increase its profits" (Cash, 2014). This view has been widely debated in the business community and might mislead executives to think that activities within CSR will not drive profits. The notion has been countered in several studies, as will be discussed in the literature review section.

One company that has helped to organize the entire world of corporate social responsibility is called CSRHub (www.csrhub.com). This company is identified as the world's largest CSR intelligence database and thought leader in this space. Through their work, across +139 industries, they have divided CSR principals into four distinct components. These four elements are as follows: Environmental, Community, Employees, and Governance. (See Table I below). Thus, an opportunity exists to identify: (a) if CSR is having any impact on corporate profitability: and if yes (b) which specific component(s) should firms be concentrating on in CSR to have the biggest impact on corporate profitability.

2. Literature Review

The influence of CSR on companies' performance, especially financial performance has become a vital issue in corporate governance and management across the globe. There are two views that are held amongst researchers regarding CSR's relationship to CFP that have been studied over recent years. The first view is the conventional view which believes that in order to be socially responsible, additional expenses will be incurred resulting in CSR being a very costly initiative to undertake. For example, investments in pollution reduction, employee benefits packages, donations, and sponsorships to the community are all socially responsible actions that corporations have undertaken. One conventional view maintains that these expenses will deteriorate profitability and lead to a 'competitive disadvantage' for the firm (Alexander & Buchholz, 1978).

The second view that has been researched since 1984 is an opposite view promoted by stakeholder theory. Stakeholder theory rests on the notion that the dissatisfaction of any stakeholder group can potentially affect economic returns, and even compromise a company's future. (Clarkson, 1995). Because, stakeholders are not only external, managers should take account of all individuals and groups with a stake in or claim on the company, not just shareholders. (Melé, 2008). If managed properly, CSR will not only improve the satisfaction of these stakeholders, but also lead to improved financial performance (Aver & Cadez, 2009). For example, satisfied employees will be more motivated to perform effectively. Satisfied customers will be more willing to make repeat purchases and recommend the products to others. Lastly, more satisfied suppliers that are pleased with the relationship may be more willing to provide discounts, etc.

As is seen in Table 2, there have been many studies that have found a positive, negative, no relationship at all or a U-shaped/inverted relationship between CSR and CFP. As Table 2 outlines, there have been three studies that identify a positive relationship between CSR and CFP. These suggest that being socially responsible improves profitability. It can be concluded from these studies that CSR has a positive effect on CFP. Therefore, it is likely that socially responsible investments have a positive, rather than a negative effect on shareholder value (Moser & Martin, 2012), meaning that CSR is also favorable for the shareholder.

Table 1. Definitions

Variable	Scheme		
	Subcategory	**Description**	**Data Range**
Community %	Human rights, supply chain, product quality & safety, product sustainability, community development, philanthropy	The Community Category covers the company's commitment and effectiveness within the local, national and global community in which it does business. It reflects a company's citizenship, charitable giving, and volunteerism. This category covers the company's human rights record and treatment of its supply chain. It also covers the environmental and social impacts of the company's products and services, and the development of sustainable products, processes and technologies (CSRHub Data Schema Description – https://esg.csrhub.com/csrhub-data-schema).	0-100% (compared to all companies rated by CSRHub)
Employees %	Diversity, labor rights, treatment of unions, compensation, benefits, training, health, worker safety	The Employees category includes disclosure of policies, programs, and performance in diversity, labor relations and labor rights, compensation, benefits, and employee training, health and safety. The evaluation focuses on the quality of policies and programs, compliance with national laws and regulations, and proactive management initiatives. The category includes evaluation of inclusive diversity policies, fair treatment of all employees, robust diversity (EEO-1) programs and training, disclosure of workforce diversity data, strong labor codes (addressing the core ILO standards), comprehensive benefits, demonstrated training and development opportunities, employee health and safety policies, basic and industry-specific safety training, demonstrated safety management systems, and a positive safety performance record (CSRHub Data Schema Description – https://esg.csrhub.com/csrhub-data-schema).	0-100% (compared to all companies rated by CSRHub)
Environment %	Environmental policy, environmental reporting, waste management, resource management, energy use, climate change policies and performance.	The Environment category data covers a company's interactions with the environment at large, including use of natural resources, and a company's impact on the Earth's ecosystems. The category evaluates corporate environmental performance, compliance with environmental regulations, mitigation of environmental footprint, leadership in addressing climate change through appropriate policies and strategies, energy-efficient operations, and the development of renewable energy and other alternative environmental technologies. Also included are disclosure of sources of environmental risk and actions to minimize exposure to future risk, implementation of natural resource conservation and efficiency programs, pollution prevention programs, demonstration of a strategy toward sustainable development, integration of environmental sustainability and responsiveness with management and the board, and programs to measure and engage stakeholders for environmental improvement (CSRHub Data Schema Description – https://esg.csrhub.com/csrhub-data-schema).	0-100% (compared to all companies rated by CSRHub)

Governance %	Leadership ethics, board composition, executive compensation, transparency and reporting, stakeholder treatment.	The Governance category covers disclosure of policies and procedures, board independence and diversity, executive compensation, attention to stakeholder concerns, and evaluation of a company's culture of ethical leadership and compliance. Corporate governance refers to leadership structure and the values that determine corporate direction, ethics and performance. This category rates factors such as: are corporate policies and practices aligned with sustainability goals; is the management of the corporation transparent to stakeholders; are employees appropriately engaged in the management of the company; are sustainability principles integrated from the top down into the day-to-day operations of the company. Governance focuses on how management is committed to sustainability and corporate responsibility at all levels (CSRHub Data Schema Description – https://esg.csrhub.com/csrhub-data-schema).	0-100% (compared to all companies rated by CSRHub)

Table 2. CSR-CFP Relationship

Nature of the CSR–CFP Relationship	Representative References
Positive	Al-Tuwaijri et al., 2004; Burnett & Hansen, 2008; Rodgers et al., 2013
Negative	Baird et al., 2012;Peng & Yang, 2014
No relationship	Alexander & Buchholz, 1978; Aupperle et al., 1985; Sun et al., 2010; McWilliams & Siegel, 2000.
U-shaped/inverted	Barnett & Salomon, 2012; Bowman & Haire, 1975.

However, there are contradictory studies listed in the table as well. Two suggest that there is a negative relationship between CSR and CFP. These findings are consistent with a view that social responsibility incurs costs and deteriorates profitability. It can be said that this type of behavior is socially irresponsible, because the sole responsibility of firms is profit. However, the negative link between CSR and CFP does not imply the complete abandonment of socially responsible corporate actions. Many managers believe it is important to be good corporate citizens even when doing so is at the expense of shareholders (Moser & Martin, 2012) In addition, shareholders can also be ethical and may require CSR action, even at the cost of reduced financial performance (Mackey et al., 2007). The third documented relationship is no relationship. Lastly, four studies suggest that being socially responsible does not improve profitability, but it also does not deteriorate it. The positive and negative effects of CSR appear likely to cancel each other.

The last detected relationship between CSR and CFP was U-shaped. Barnett and Salomon (Barnett & Salomon, 2012) found that companies with low CSR performance have high CFP, companies with moderate CSR performance have lower CFP, whereas companies with high CSR performance have the highest CFP. Interestingly, a much earlier study by Bowman and Haire (Bowman & Haire, 1975) documented similar results, an inverted U-shaped/inverted relationship. These studies suggest that mediocre CSR is related to the highest financial performance, whereas low and high CSR are related to lower financial performance.

In reviewing these studies, clear and coherent evidence is lacking on the relationship between CSR and CFP. Possible explanations for such inconclusive findings have been offered by many authors (Surroca et al., 2010.) These include, among others: (1) the poor theoretical foundation of the CSR concept (Ruf et. al., 2001); (2) the omission of relevant variables in model specifications (McWilliams & Siegel, 2000); (3) the lack of a clear direction of causality (Waddock & Graves, 1997);

and (4) measurement issues (Davidson & Worrell, 1990) and sampling limitations (Van & Gössling, 2008).

As seen in Table 1, sustainability is a key factor that cuts across virtually all of the four components of CSR. The initial concept of sustainability was initiated in 1962 by Rachel Carson's, "Silent Spring" which researched catastrophic levels of agricultural pesticides leading to damages in human and animal health (Carson, 1962). Building on this initial awareness, there has been a steady increase in the quantity and quality of research related to CSR and its relevance to corporate profitability and revenue. Based on the analysis conducted, a greater amount of research has been performed by third-party firms rather than internal analysis by those organizations that follow sustainable business practices. One consideration is that companies are mindful of communicating genuine intentions for social and/or environmental improvements rather than risk perceptions that they are greedily seeking revenue performance because of following sustainable practices. Additionally, there are different levels of importance for sustainability issues across industries that are challenging to capture, measure, and accurately apply to confirm relevance (Khan et al., 2015).

Specific to the linkage of sustainability and revenue performance, in 2010, the Boston Consulting Group partnered with the World Economic Forum to identify firms that had the most effective sustainability practices in the developing world. Results from the 1,000 companies that qualified for the study showed that more than 12 consistently generated above-average growth rates and profit margins (Knut, 2013). Also, in 2010, an article entitled "Does Corporate Social Responsibility Influence Profit Margins?" studied mechanisms for CSR that could increase profits specific to textile companies in the Norwegian market with a focus on distinguishing achievement of average profits versus above-average profits with CSR (Blomgren, 2010).

According to Andy Fyfe with the B-Corporation (https://bcorporation.net/), a business that is comparable to what USDA Organic certification is to milk. Companies are not looking to be certified for an increase in sales, but rather it is the attractiveness to lure in talent to work for an organization that represents higher standards. According to Andy, it is the human resource effect coupled with the increased draw to investors because the organization commits to meeting rigorous standards of social and environmental performance, accountability, and transparency. There are more than 2,500 b-corps in the world, but the B-Corporation does not measure if their certification yields revenue improvement. As a final example of previous analysis conducted, CH2M Hill produced a white paper report in 2013, "Sustainability Goals that Make an Impact," that determined firms that set tangible, public sustainability goals do improve their financial and environmental performance. Their methodology included analysis of publicly available sustainability and financial data, third party analysis and rankings, and interviews with sustainability executives (Hardcastle, 2013).

3. Hypothesis

H1: There is a positive relationship between corporate profits and corporate social responsibility specific to corporate governance, community, employees, or environment. Higher involvement in CSR will lead to higher corporate profits.

4. Research Design and Methodology

The sample is composed of 100 randomly selected companies from the 2017 Fortune 500 from a rating system developed by CSRHub (https://www.csrhub.com/), which has over 17,000 companies listed. CSRHub provides consistent and unbiased data by performing the following steps: (1) map to a central schema in which 12 subcategories roll up into four categories

(Education, Governance, Employees, and Community); (2) convert to a numeric scale of 0 to 100 (100=positive ranking); (3) normalize the scores from different data sources for the same company to remove bias and create consistent ratings; (4) aggregate and weigh each source based on estimated credibility and value at the subcategory level and then aggregate to the category level; (5) trim the ratings that do not have enough information; and (6) research each rated company and attempt to determine which industries it participates in. Included in this data were 4 independent variables as defined by CSRHub, i.e., community, employees, environment, and governance. The purpose of the research is to determine whether CSR has an impact on the profitability of a company; also, if all or which segments out of community, employees, environment, or governance have a significant positive or negative influence. The dependent variable is a firm's profits (as percentage of revenue). The independent variables are community percentage; employee percentage, environment percentage and governance % (please refer to Table 1 for definitions)

The expectation is that, while not all four segments may have a significant impact on profit margin, they will, at least taken together, have an effect. When looking at the community percentage, it is hypothesized that if a company is active in its relationship with the community, there would be an uptick in their profit margins. The same expectation would go for the manner in which a company treats its employees. If an employee is treated more fairly and is fairly compensated, this would result in a more productive employee leading to a potential change in profits. This expectation could also carry over to the environment as well. If a company is strict on its waste and energy usage, this would transfer to an improvement in profits. The last segment of the model is governance. It is not as clear whether this segment will have an impact on profits. The compensation of the senior leadership team may have an impact on profits, but does that same thought process have any effect on the stakeholder?

The data was studied by using Statistical Package for the Social Sciences or SPSS. Using SPSS, the data was analyzed by using a multiple regression model. This model was designed to help answer the research question: does the community, employee, environment, and governance segments of CSR influence the profit margin of a company?

5. Analysis and Results

Figure 1 below identifies the multiple linear regression model summary and overall fit statistics for all the independent CSR variables of % Governance, % Employees, % Environment, and %, Community and the dependent variable of a Profit as a percent of revenue. It has been determined that the R^2 of the model is 0.145, which indicates that there is 14.5% of variability in the profit ratio that can be explained by the CSR components, as defined by the Community, Employees, Environment, and Governance ratings. The standard error of the estimate of 0.09.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.381[a]	0.145	0.109	0.091042

a. Predictors: (Constant), Governance, Community, Environment, Employee
b. Dependent Variable: Profit Margin

Figure 1. Model Summary

In Figure 2 below the significance value of the model is 0.005, which is below critical value of p-value of 0.05. This indicates that the regression model is significant. Hence, there is strong statistical evidence that CSR components in the aggregate are a significant predictor of corporate profitability.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.134	4	0.033	4.036	.005[b]
	Residual	0.787	95	0.008		
	Total	0.921	99			

Figure 2. Regression model significance

Figure 3 shows the detailed results of the regression. Column B identifies the profit for each CSR component. For a 1% increase in each component, there is a corresponding impact reflected in column B. The significance level was drawn at three decimal places to measure impact. Community is zero, indicating that there is nothing significant added to profit margin based on spending against this component. Employee is 0.002, the highest indicator of the four variables. For Employee, for every 1% increase there is an increase of 0.002% in corporate profitability. Lastly, Governance shows -0.001, which indicates that this component has a negative impact on profit margin.

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	-0.004	0.028
	Community	0.000	0.001
	Employee	0.002	0.001
	Enviornment	0.001	0.001
	Governance	-0.001	0.001

a. Dependent Variable: Profit Margin
b. Predictors: (Constant), Governance, Community, Environment, Employee

Figure 3. Regression Unstandardized Coefficients

Figure 4 below is an indication of each of the predictor's significance as it relates to profit margin. Numbers less than 0.05 are statistically significant. In line with the information in Figure 4 below, community holds the least significance through the table below registering the highest p-value (0.867). Of the four components, Employee is the only independent variable to signal a statistical significance, with p-value falling below 0.05 at 0.013. Environment and Governance are both greater than the expressed threshold for significance.

Coefficients[a]

Model		Sig.
1	(Constant)	0.898
	Community	0.867
	Employee	0.013
	Enviornment	0.427
	Governance	0.377

a. Dependent Variable: Profit Margin
b. Predictors: (Constant), Governance, Community, Environment, Employee

Figure 4: Regression Significance of Coefficients (p values)

In summary, the significance of the coefficient below the 0.05 significance threshold allows the rejection of the null hypothesis i.e. that there is no relationship between corporate profits and corporate social responsibility specific to Corporate Governance, Community, Employees, or Environment. This is in line with the R2 value that there is a 14.5% of variability in profit ratio that can be explained by CSR values of Community, Employees, Environment, and Governance. Diving into each value separately, the model shows that the only value of significance is Employees. The value of Employees has a p-value of 0.013 which is less than 0.05. This allows rejection of the null hypothesis confirming that this CSR predictor may well have an impact on the profit of the company. Community has a significance level of 0.867, Environment has a level of 0.427, and Governance was found to have a significance level of 0.377. These scores were all above the threshold of 0.05 allowing us to accept the null hypotheses and determine that these CSR values are not significant and do not play a major role in determining the profit used a coefficient table. Very important is that for every 1% increase of Employee percentage of CSR component, there was 0.002% increase in profit margin.

6. Conclusions

In conclusion, the research done for this paper was to see if a relationship exists between CSR and corporate profit margin. In addition, it was to determine if Community, Employee, Environment, and Governance had any effect on the dependent variable of profit margin. With the use of multiple regression, it was determined that there may well be a relationship that exists between CSR and CFP. In addition, while the CSR values of Community, Environment, and Governance are important, they were not solely significant enough to influence the profit margin of a company. In this study, the only CSR value deemed significant by the models was the Employee component. Per the research and modeling for every 1% increase in employee % component of CSR, there is a corresponding increase of 0.002% in corporate profitability.

It should be noted that only 14.5% of the variation in the dependent variable (Profit Margin) is influenced in the full model. This seems logical as there are many other exogenous variables that could affect profit margin of a firm e.g. productivity, debt, the value proposition etc.

The findings show that there is a linkage between profit margin and CSR. In addition, the Employee component of CSR was most important. This linkage is inclusive of the attributes of Employee i.e. diversity among employees, labor rights, treatment of unions, compensation, benefits, training, health, and worker safety. While there is a relationship between employee CSR and profit margin, there was not a definitive causation where CSR could create major higher profit margins. It is important to note that it is imperative that companies continue their efforts in Community, Environment, and Governance. If these areas are not held constant, there could be a potential impact on the overall profit of the company.

7. Recommendations

It is recommended to take this study several steps further with initially, a deeper dive in the components of Community, Employees, Environment, and Governance. How do these components break down? What are the segments that are causing an impact, whether negative or positive? The predictor variable Employees was found to have a significant impact on profit margin, but within Employees what is moving the needle? Was it the diversity of employees, labor rights, treatment of unions, compensation, benefits, training, health, or worker safety? Within each component, are there places that companies should focus more time and effort? It may be found that some pieces are completely negating the significance of others. Thus, dropping such a piece could prove to make that component significant. From a methodology viewpoint, a Bayesian probabilistic approach could be used in the future to augment this study. It could be used to further show how various sub-categories may contribute to the argument considered.

The demand for socially responsible actions will continue to intensify as cultural awareness and expectations for sustainability increase from Employees, Communities, and the population as a whole. A plethora of information is available for demand and how companies are addressing sustainability. However, a clearer disclosure of the actual expenditures made by companies needs to transpire. The debate for mandatory disclosure in financial statements of the direct expenses for CSR has been ongoing, yet does not appear to be likely to occur soon. Upon review of many countries' policies, there were only a few that require close to what France and India have implemented:

- France: 2010 – Article 225 requires CSR reporting for listed companies with verification by a third-party.
- India: 2013 – The Companies Bill 2013 mandates that companies with a net worth more than $77 million USD to spend at least two percent of their three-year average annual net profit on social welfare initiatives and must be included in their annual reports (Initiative for Responsible Investment, n.d.).

Lastly, the addition of more independent variables such as diversity in executive leadership could be explored, i.e.:

- Gender: In 2016, 21 CEOs of the Fortune 500 companies were women and grew to 32 (a 52% increase) on 2017's list. Is there a significant relationship in CSR spending?
- Age: Is there a relationship between the age of a CEO and CSR spending?
- Multinational or Domestic Corporation: Is there a relationship between CSR spending and operating in more than one country?

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Optimal Stormwater Runoff Path by Identifying Gravitational Potential Energy Function with the Least Energy Path

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Abstract

This study identifies a stormwater runoff path that has the least energy value, which is proposed to be defined from the principle of the potential energy function. The runoff path is one of the most important issues for underdeveloped and new cities. Due to the dangerous impact associated with global warming increasing the number of rain flood incidents around the globe, this study proposes a model to predict the stormwater runoff path based on the least energy principle. Previously, researchers have used many techniques and models in designing the stormwater runoff path, yet many of those existing techniques and models are not sufficient with the enormous environmental warming changes. This study investigates the optimal stormwater runoff path by using the principle of potential energy function for a grid mapping in a city. The grid has three coordinates (longitude, latitude, and elevation) that simulate the city's natural terrain. The proposed model uses the three coordinates in the potential energy function to calculate the energy value of the stormwater runoff path. It is based on the gravitational potential energy of each elevation of a city terrain grid. Moreover, the study used an optimization method (Dijkstra's algorithm) to find the path that has the least energy value among the infinite number of paths between two points of different altitudes and longitude. The least energy path, the path between the two distinct starting and ending points, was gained as a result of this study. The path can be generated for predicting or designing the stormwater runoff path for any city. The results and performance of the proposed design have been tested and reported.

1. Introduction

Various simulation models are proposed and used to design the stormwater runoff path (Roy, 2009; Carter, 2007). A number of multiple stormwater management strategies have been proposed in recent years, such as Low Impact Development (LID) and best management practices (BMP) in the United States (USEPA, 2000; Liu et al., 2017; Liu, Yaoze, et al., 2018), water-sensitive urban design (WSUD) in Australia (Heathcote et al. 2007), and sustainable drainage systems (SuDS) in the UK (Scholz and Grabowiecki, 2007). LID is widely used in developing stormwater management for urban regions yet not for city or regional levels (Dietz, 2007; Ahiablame et al., 2012). However, the United States Environmental Protection Agency (USEPA, 2000) developed a stormwater management model (SWMM) in 1971, involving rainfall-runoff simulation of hydrology, hydraulics, and water quality at a small scale (Dietrich, 2015; Rosa et al., 2015; Li, Chunhui, et al., 2019). One review article was focusing on the Stormwater Management Model and studied many peer-reviewed articles for calibrating and validating the performance of the model (Niazi, Mehran, et al., 2017). As a conclusion, the article found that SWMM can be widely used as a flexible simulation tool to solve many problems related to stormwater. Later, researchers utilized GIS-based grids to apply SWMM at larger scales (Barco et al., 2008). For better planning, a new methodology which uses the corporation between the calculation of hydraulic and hydrological was applied to design stormwater path in the urban areas (Allende-Prieto, Cristina, et al., 2018).

This research investigates the optimal stormwater runoff path for underdeveloped and newly designed cities based on the least energy path principle. It is rather challenging to find and model the optimum path for the rainfall runoff path for large-scale cities. However, the goal is to attain the city grid coordinates with the elevation of each point on a city terrain map. The assumption of the least energy path was basically derived from three coordinates (longitude "x", latitude "y", and elevation "z"). The longitude and latitude coordinates represent the grid of the city terrain map, where the elevation coordinate represents the height of the grid which is essential in calculating the gravitational potential energy. The method of the least energy path depends on the principle of stationary potential energy (Zwawi et al., 2017). It is used to identify the optimum path that has the minimal energy among all other different paths from a starting point to an ending point (Zwawi, 2015). This method is derived from the method of global minimum potential energy and local minima potential energy which leads to the lowest energy among the paths (Lewars, 2010; Quapp, 1984; Scharfenberg, 1980). Also, the potential energy surface with the path is used to find the reaction of molecules (Schlegel, 1995; Nichols et al., 1990; Basilevsky et al.,1981).

The starting point was defined as the location on the map where the stormwater started, and the ending point is the targeted location on the map where the stormwater is accumulated. The assumption of the least energy path has recently been successfully applied to many applications. Zwawi (2017) utilized the least energy path principle with a computational biomechanical model to investigate all hip dislocation potential paths in order to find the path with the minimum resistance (or energy). They used an optimization routine to determine the optimum path. This path is defined and selected by using Dijkstra’s algorithm (Dijkstra, 1959; Mitchell et al., 1987; Aleksandrov et al., 2013). Their results are in accordance with clinical observations from previous models of a pathway with the least energy requirement.

This research helps city designers to predict a city stormwater runoff path by utilizing a validated computational mechanical model for the path of least energy that is required from the starting point to the ending point of the stormwater. Moreover, the results of this study can be used to validate the existing stormwater path and modify it to match the least energy path which is identified by this study, and apply a modification based on the results.

2. Methodology

2.1. Model

In this research, an assumed city with a sloped terrain map was used with three concerned variables (latitude "x", longitude "y", and elevation "z"). These variables were embedded into a numerical code to calculate the Gravitational Potential Energy (GPE) values at each point on the grid map. The points on the grid were defined on the map by using (x, y) and named with numbers. Then, the GPE values were calculated by using the geological elevation "z" for each point. An energy surface map for the proposed city was generated by using the latitude, longitude, and GPE values for the points on the city map grid, as demonstrated in Figure 1.

Finally, Dijkstra's algorithm was used to find the optimum path that has the least energy amount based on the stationary potential energy method. Moreover, in case the different paths have the same energy values, the algorithm will find the path that has the shortest distance which is selected for the optimal runoff path. This path was defined as the optimal stormwater runoff path with the least energy compared to all other paths.

2.2. Model Constraints

For this model, the constraints can be defined by the model which are the starting and the ending points of the path. The design of the model requires two points to find a path. The first point was assumed to be the stormwater starting point on the map and the second point is where the journey of the stormwater ends. A simple example of a county with sloped terrain can be seen in Los Angeles County, USA where the highest point of Mount San Antonio (3,068 m elevation) is to the East and the Pacific Ocean (sea level elevation) is to the west. Therefore, this sloped terrain has a stormwater starting point at the Mount San Antonio and the end point is at the city coast.

2.3. City Grid Terrain Map

First, a list of x and y point coordinates of 100 x 100 were assumed to be the latitude and longitude of a city. Then, postulated elevations (of meter unit altitude) were added for each (x,y) grid to set a sloped terrain map, as in Figure 1. After that, these data points were embedded to the code to calculate the GPE for each point. Finally, the values of the GPE were transferred to Dijkstra's algorithm to find the least energy path.

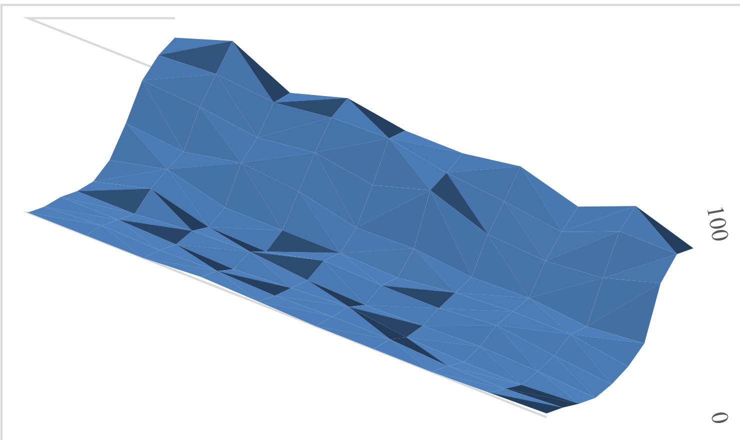

Figure 1. City grid terrain map showing slopped terrain and altitude in meters

2.4. Energy Method

The idea of predicting the runoff path by using the least energy concept was considered in this study based on previous studies on stormwater runoff and analyses of least energy paths. The least energy concept was based on the study of the city terrain grid map. The city map has two coordinates (latitude and longitude), yet the elevation is required as the third altitude coordinate for the model to calculate the gravitational potential energy.

As discussed previously, the optimum stormwater runoff path was suggested to be predicted by using the method of GPE. The gravitational potential energy "Ω" was numerically calculated by using the elevation "z" in meters of each point on the grid of the city terrain. The reference for the grid height is the sea level. Another variable considered in computing the GPE is the mass, which is calculated by using a density of 1,000 Kg/m3 and a volume of 1 m3. Therefore, a computer code was modified to calculate the GPE, changing the grid location of the map and the corresponding elevation for the city grid.

$$\Omega = m.g.z$$

$m = 1\ Kg$

$g = 9.81\frac{m}{s^2}$

Where the GPE "Ω" is a function of stormwater mass "m", gravitational acceleration "g", and the elevation of the city map grid "z".

2.5. Dijkstra's Algorithm and Least Energy Path

There are an infinite number of paths between any two points in a map grid (Zwawi, 2016), as shown in Figure 2. However, only one path has the least energy to displace from one point to another among all other paths. This point is verified by the principle of stationary potential energy $\frac{\partial \Omega}{\partial z_i} = 0$.

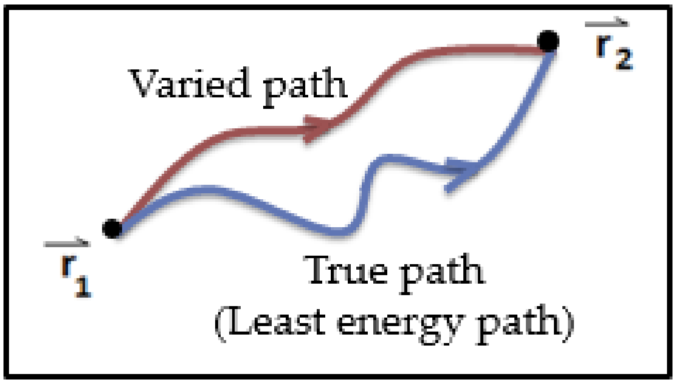

Figure 2. Energy path between two locations is infinite

In the beginning, two points on the city map were selected (xi ,yi) and (xj ,yj). The "i" notation represents the starting point of the stormwater. However, the "j" notation is the ending point of the stormwater. These two points were defined in Dijkstra's algorithm as the starting and ending points of the code. An Excel spreadsheet with all grids with the calculated GPE was also uploaded to the algorithm. The algorithm starts predicting the path by the starting point and finding the adjacent point on the terrain grids to the second point, then calculates the GPE difference between the starting point and all adjacent points. This process was repeated for all points. After finding the difference between all points (starting from the initial points and ending at the endpoint), the routine compares all paths from the desired starting and ending points and prints out the path that has the least energy amount.

Another variable was added to Dijkstra's algorithm to attain the shortest path. This variable was assumed to be the length between the grids by using the latitude and longitude values (Aleksandrov et al., 2013; Kimmel & Kiryati, 1996). This variable is added to predict the shortest path in case there were two paths with the same least energy values with different paths. Finally, the program will select the path that has the shortest length and the least energy value.

3. Results and Discussion

After using Dijkstra's algorithm to find the least energy path and the shortest distance, the findings can simulate the stormwater runoff path with the least energy. The suggested approach combines the path with the least energy and with the shortest distance. This path can be used for designing the city stormwater runoff path.

In the coding program, the starting point is selected to be node# 5 at the top of the city map and the targeted node is # 98 at the city coast. Dijkstra's algorithm calculated the energy as described earlier between the different nodes and found the path that has the least energy values. The result of the program is shown in Figure 3. It demonstrates that between nodes 5 and 98, the required energy to displace is 124.5 J, corresponding to the minimum energy among all other paths.

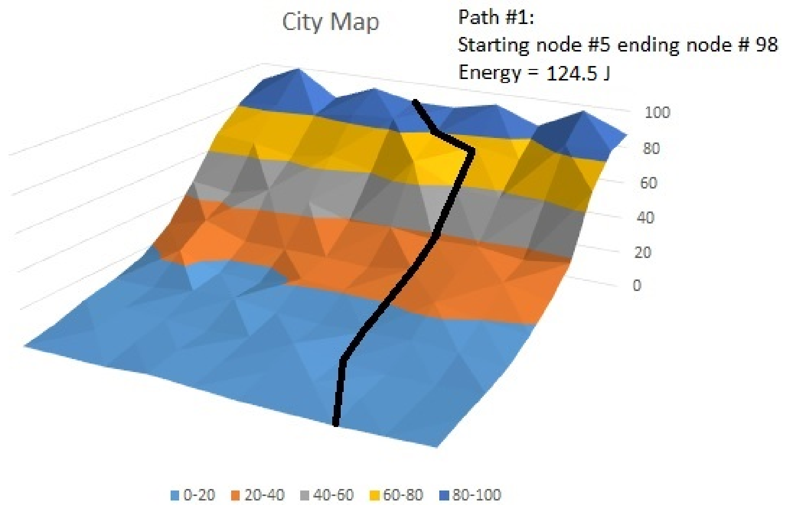

Figure 3. Path#1: Least energy path between nodes 5 and 98

In order to validate this approach, the path was forced to select another node along the path, and the energy value was calculated to be 126.8 J, which is greater than the value found by the coding program, as in Figure 4.

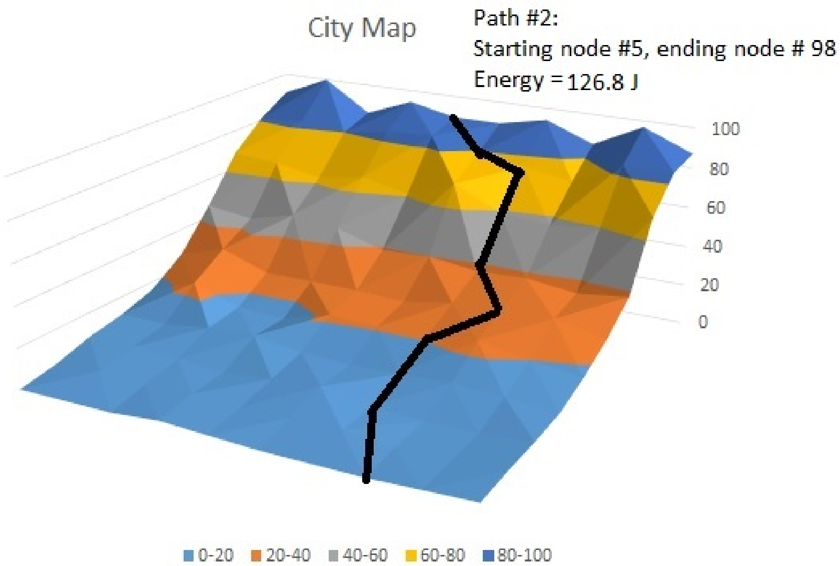

Figure 4. Path#2: Path between nodes 5 and 98 with changing one node

Another attempt was conducted for this study — the starting point is node# 5 and the ending point is node# 94, and the energy required for this path is higher than the first path shown in Figure 3. The required energy for this path is 145.3 J, as illustrated in Figure 5.

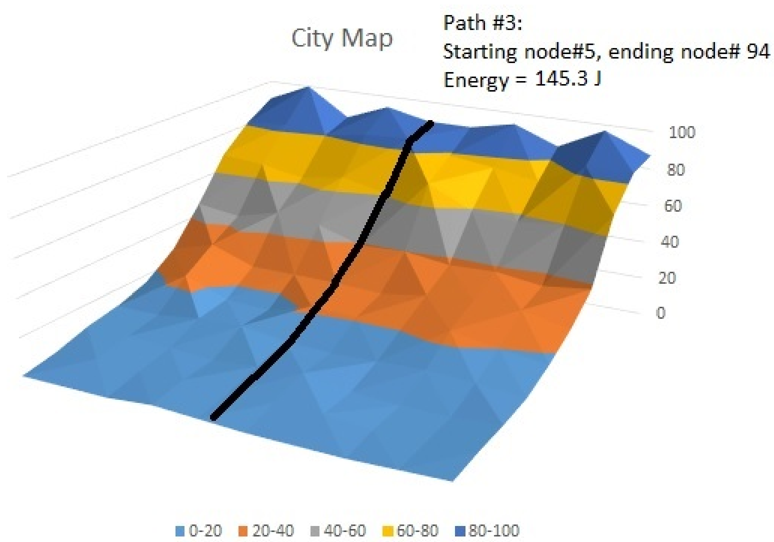

Figure 5. Path#3: Shortest path between nod es 5 and 94

The last attempt path study starts at node#5 and ends at node #99. This path requires energy of 162.4 J, which is higher than the first path, as in Figure 6.

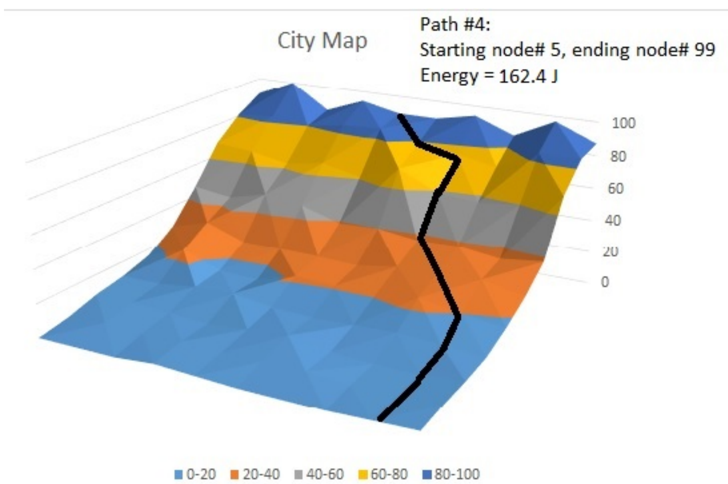

Figure 6. Path#3: Path between nodes 5 and 99

From the previous results, it can be shown that for predicting the optimum stormwater runoff path, Dijkstra's algorithm can be used to design and predict the city runoff path. The path is defined by selecting the starting point and the targeted point on the city terrain grid map. Infinite paths between any two nodes can be found, yet one path is selected with the lowest energy value when compared to other paths. Figure 1 shows how the program selects the desired path with all perspectives and variables as specified previously.

4. Conclusion

The optimized method used in this research identifies the least energy path for the stormwater runoff path successfully by applying Dijkstra's algorithm. The coded program is set based on the principle of gravitational potential energy. Several models are used in the literature review to identify the stormwater runoff path. The results of this research show reasonable and simple predicted paths. The method is built by using a city grid map with three variables — latitude "x", longitude "y", and elevation "z". On the other hand, some other variables can affect the selection and design of the path such as roads and buildings. In this research, the above variables were ellimanated because we focused on cities that is not yet built. But for established cities, the terrain map can be designed by disregarding the areas that have buildings or occupied by civil construction in order to run the algorithm in the remaining areas. Then, the gravitational potential energy is calculated by assuming the mass of 1 kg of water and the elevation z of each point. The values of x, y, and z are impeded in Dijkstra's algorithm. The algorithm calculates the energy differences between all path nodes and builds a tree of an infinite number of paths. Finally, the algorithm selects the path that has the least energy value and the shortest distance.

This optimized method is considered to be used as an offline design tool that gives a promising decision in designing the stormwater runoff path of a new city. Moreover, the proposed method can be used in designing any path that requires the least energy path.

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Mobile Device Espionage

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Abstract

Malware and hacking activities are growing among today's most popular mobile devices. These security risks are prompting companies, federal facilities, and other institutions to enact policies aimed at mitigating the amount of espionage and illegal events that can transpire on a cell phone or other mobile device. With all of the new devices and applications, publicly available, new security-related vulnerabilities continue to arise. These devices and applications are targets for attacks from malicious outside sources. Each day provides a new potential threat aimed at taking advantage of some security exploit in cell phones and mobile devices. Security analysts and experts are at a disadvantage in this war against threats because they are fighting a war without clear rules. The focus of this literature review is on cell phone and electronic device vulnerabilities, espionage in the workplace, and security solutions. This will provide an understanding of risks, threats and solutions that exist in the modern era of cell phones and mobile devices.

1. Introduction

The purpose of this research is to provide a literature review on cell phone and electronic device vulnerabilities, espionage in the workplace, and security solutions. Cell phones and other mobile devices have become ubiquitous in everyday life. According to Jones and Chin (2015), the number of mobile devices, 7.22 billion, has surpassed the worlds' population of 7.19 billion. The number of application (app) downloads is also just as staggering. Tong and Yan (2017) suggest "mobile app downloads are expected to reach 224,801 billion in 2016" (p. 22). With all of the new devices and applications publicly available, new security-related vulnerabilities have arisen. Traditional personal computers are not the only electronic devices that can be hacked or infected with viruses. Cell phones and wearable mobile devices are vulnerable to being hacked and infected as well (Shaulov & Point, 2016). These devices and applications are targets for attacks from malicious outside sources. An example of one of these external sources is a virus application acting autonomously with the goal of making mobile devices inoperable from both a software and hardware level. Any internet-of-things device is a ubiquitous device with every user representing an enticing prospect for the would-be hacker or criminal (D'Orazio & Choo, 2017). Security firms are on the front line of fighting external and internal security threats, at home and from abroad. Security analysts and experts are at a disadvantage in this war against threats because they are fighting a war without clear rules. Attackers continuously create new and innovative exploits at a lightning pace, and this technology can only be anticipated to a certain degree (D'Orazio, Lu, Choo,

& Vasilakos, 2017; Shaulov & Point, 2016; Wilosinski, 2016). Security firms can only offer protection to its customers against exploits that are known and not necessarily emerging vulnerabilities. The focus of this literature review is to provide an overview of cell phone and electronic device vulnerabilities, espionage in the workplace, and security solutions.

2. Literature Review

2.1 Cell Phone and Electronic Device Vulnerabilities

This section addresses vulnerabilities to unsuspecting cell phone and electronic device users that have the potential for their device to be hacked. D'Orazio et al. (2017) suggest that mobile security issues are not just for a particular user but also users' internet infrastructure and place of business, making workplaces vulnerable for security infractions. For example, an employee at a nuclear power plant exercising poor security practices with their cell phone could result in their device functioning as a spy for a malignant organization, unbeknownst to the employee. Smartphones have been used before as spying devices (e.g., recording audio, GPS positions, etcetera), with the user utterly oblivious to the malicious activity transpiring (Wilosinski, 2016). This section will provide an overview of currently known, published cell phone vulnerabilities that exist within modern technology.

Research has shown that cell phone attacks can reside within one of four major domain areas (Bitton, Finkelshtein, Sidi, Puzis, Rokach, & Shabati, 2018). The first area is man-in-the-middle attacks (MiTM), that consists of hijacking, interceptions, and eavesdropping activities (Bransfield-Garth, 2010). The second area is a phishing attack that consists of fake websites, links, and other fraudulent pages to coax information out of victims. The third area includes application attacks comprised of Trojan applications and pop-ups. Lastly, weak authentication attacks, which consist of password cracking and/or an absence of or failure to utilize a device locking mechanism on a cellular phone (Bitton et al.; Shaulov & Point, 2016). These domain areas represent the currently known external cell phone vulnerability avenues.

Jones and Chin (2015) suggest that participants did not have appropriate smartphone security practices in place. They also suggest that participants were more likely to trust downloaded applications on their smartphone device, without question, and assume that nothing negative can come from such actions. This research coincides with research by Thompson, McGill, and Wang (2017), which suggests that users do not often understand the technology associated with these devices used daily and do not quite understand how to protect themselves adequately. In both of these studies by Jones and Chin (2015) and Thompson et al. (2017), participants' behaviors were risky and not focused on being security conscious. Examples of unsafe behavior included: not logging off potentially sensitive sites (e.g., email), opening unknown attachments, downloading unknown applications, and storing pins and passwords. The findings indicate that until users become more aware that security risks exist, they would continue to be cavalier in their actions (Jones & Chin, 2015). And while app stores purport to screen applications for malicious intent, these are not infallible processes. In early 2016, the security application Lookout reported over a dozen separate applications available for download that they identified as malicious, having snuck through Google's review process (Schiwy, 2016).

These previously identified risky behavior practices allow what Wilosinski (2016) refers to as social engineering to transpire. A simple example of this is a compromised wireless hotspot resulting in a user granting unlimited access to their device. Social engineering consists of four types of attacks, called phishing, vishing, smishing, and exploiting social media accounts. Each of these four attacks result in a tricked victim taken advantage of while using a mobile device.

Phishing refers to "masquerading as a trustworthy entity" (Wilosinski, 2016, p. 2). Vishing refers to "tricking a victim into calling a phone number and revealing sensitive information" (Wilosinski, 2016, p. 2). Smishing refers to "tricking someone via messaging into downloading malware onto their mobile device" (Wilosinski, 2016, p. 2). Lastly, exploiting social media accounts refer to utilizing publicly available information found on social media for exploitation. Social media consists of applications similar to, but not limited to Facebook and Twitter. According to Chen et al. (2017), a scammer can utilize social media accounts to specifically tailor a con to a person to the point where it looks and feels authentic. However, an attacker could use any combination of the four types of attacks of social engineering to be able to cause damage to a target (Wilosinski, 2016).

Lock screen passcodes are often the first line of defense against physical attacks. In 2014, over 5 million mobile phones were either lost or stolen from Americans and without a passcode to enter the device, data stored on the phone or online accounts, such as banking, could be easily accessed. Yet, a 2016 Mobile Security Report discovered that as high as 43 percent of mobile device users do not have "a passcode, Personal Identification Number (PIN), or pattern lock" enabled (NowSecure, 2016).

However, when Android users do elect to have a locking mechanism on their phone, they use a password system identified by a password pattern drawn by the user's finger. If the device is left unattended, a malicious source could do what Aviv, Gibson, Mossop, Blaze, and Smith (2010) call a smudge attack. The researchers concluded that they could crack into a user's Android device by extracting the pattern of hand-oil residue left on an Android cellular phone. Further, Android devices have been infamous for being left unpatched against known vulnerabilities, fixes that frequently come with software updates. In 2016, NowSecure reported results of a mobile security test run via an open-source application that revealed 82 percent of Android devices that ran their app were susceptible to at least one vulnerability and almost 25 percent of mobile applications include at least one high-risk flaw in their security (NowSecure, 2016). There are also risks for iOS devices. When a device pairs with another device through Bluetooth or USB, a folder is stored on each of the devices. This folder contains the pairing record information to all the devices that trust this source. However, according to Zdziarski (2014), this pairing folder can be used to crack into the other devices. Another area of risk for iOS devices is fraudulent authorization certificates. These authorization certificates tell a device that it is genuine and not malignant that resulted in applications uploaded to the Apple application store that masqueraded as valid applications that actually contained malware (D'Orazio & Choo, 2017).

Wearable devices that are standalone or paired with cellular phones, as well as personal computers, are becoming more widespread and socially acceptable (Mills, Watson, Pitt, & Kietzmann, 2016). Some wearable devices are life-imperative such as a real-time blood-glucose contact lens monitor which has the potential to be hacked through providing erroneous messages. This has the potential to hospitalize the user or result in a fatality. Wearable devices and cell phone devices are not regulated and therefore cannot be safeguarded from security infractions.

2.2 Espionage in the Workplace

The thought of espionage conjures up potentially accurate portrayals of images in popular culture such as of James Bond in a fancy tuxedo secretly traveling to exotic locales (Beim, 2018). It can be defined in many ways but is described by using human agents or technology to gain access to information not publicly available (Espionage, 2018). Winkler (2005) who is a former National Security Agency employee had his team perform an espionage simulation at a Fortune 500 company on the U.S. East Coast to identify how simple it can be for corporate spies to infiltrate a company. However, the theft of intellectual property is an invention that dates back to the invention of private enterprises (Tales from the front line of corporate espionage, 2012). The Chinese guarded their monopoly on silk production but approximately 1,800 years ago, monks smuggled silkworm eggs out of China using bamboo walking sticks that was the first step to breaking the early Chinese monopoly. This section addresses deliberate theft of confidential information for espionage. Today, with the use of mobile devices, organizations are challenged with safeguarding against espionage as taking photographs of factories and businesses of trade secrets classifies as espionage (King and Bravin, 2000). Pacini et al. (2008) discusses how espionage activities can be conducted by an array of individuals such as "current and former employees, competitors, foreign governments, independent contractors, vendors, business intelligence analysts, and others" (p. 131). Furthermore, "trade secret fraud activities include customer lists, pricing strategies, formulas, compilations, financial information, processes, design manuals, strategic and marketing plans, and other proprietary information" (Pacini et al., 2008, p. 131).

Espionage activities are common among developed nations and many lesser-developed ones in activities involving spying and eavesdropping even outside of hostile states (Baker, 2003; Beim, 2018; Coppins, 2010). News articles continuously reveal cyber-attacks ranging from sabotaging government websites to stealing important information immediately to even delayed-action malware acting as time bombs in gaining access to critical infrastructure information (Kingsbury, 2010; CNBC, 2017). Pun (2017) suggests that espionage is not any different in the challenges brought by cyber space making cyber defense protections more necessary due to the growing amount of information stored and potentially available. Pun (2017) also suggests how there are "According to NATO Secretary General, Anders Fogh Rasmussen, there are now more than 100 daily cyber intrusion attempts on NATO headquarters, and over 1,000 daily cyber intrusion attempts on U.S. military and civilian networks" (p. 355-356).

Das and Khan (2016) suggest that employees' use of their personal smartphones has pushed the Bring-Your-Own-Device (BYOD) phenomena and makes it widely supported by organizations. However, the challenge with BYOD programs is the potential for security infractions. These programs bring additional anytime-anywhere capability to organizational computing (Harris & Patten, 2014) while bringing about a mobile revolution while creating a gap between academic and business aspects of information security (Silic & Back, 2014). Salifu (2008) conducted a literature review on the impact of internet crime on individuals, organizations, businesses and government. The practical implications identified is internet crime is a global issue requiring the support of both developed and developing countries to resolve because internet crime investigations trace evidence from more than one country requiring partnerships between multiple countries in order to conquer espionage. Pun (2017) suggests that espionage's permissibility under international law remains largely unsettled building upon Salifu (2008) research with espionage being a global matter.

2.3 Security Solutions

Pacini et al. (2008) suggests steps businesses can take that to preserve secrecy to include legal remedies and internal controls to protect trade secrets that refer to any information that has value because it is not common information. The primary means of enforcement available to those that fall victim of their trade secrets being pirated is a civil lawsuit filed under the Uniform Trade Secrets Act (UTSA). In order to pursue a civil suit for damages, a claimant must be able to prove five items. These items include the claimant being able to prove an existence of an actual trade secret, the reasonable steps the claimant took to preserve secrecy, the independent economic (potential) value the trade secret holds, the misappropriation of the trade secret, and the actual loss incurred by the misappropriation. Organizations will need to provide evidentiary support to indicate that information is a secret and that the defendant secured the secret using improper means (Grubbs, 2005). Organizations can protect against internal threats by having employees sign a confidentiality agreement to ensure understanding by the employee to protect a trade secret and to have any facility visitors such as customers, suppliers or employee family members to sign a non-disclosure agreement (Gaffney & Ellison, 2003; Van Arnam, 2001). Furthermore, employers must formally remind employees to continue to protect the company's trade secret as a duty of confidentiality even after employment with the company has ceased (Gaffney & Ellison, 2003). According to the UTSA, obtaining knowledge of trade secret using improper means includes anything from theft to breach of a duty to maintain secrecy to any form of espionage such as through electronic portable devices (Pacini et al., 2008). Pacini et al. (2008) discusses how the claimant under the UTSA must establish that the defendant used or disclosed to another party the trade secret in addition to wrongful acquisition of the secret. The Economic Espionage Act of 1996 (EEA) also applies because it is a federal statute that criminalizes the theft of trade secrets by industrial spies and foreign governments. The definition under the EEA includes theft that could include a portable electronic device to steal trade secrets such as taking pictures, uploading, downloading and transmitting trade secrets.

However, organizations can also be proactive in organizational solutions to security through enhanced communication. Organizations need practices, policies, procedures and processes in place to help safeguard their trade secrets through providing training to employees. The training would involve topics such as avoiding risky behavior, social media practices, password practices, device specific vulnerabilities including cell phone brands and wearable devices, and public hotspot vulnerabilities. New employees need training on these and existing employees need refresher training. The training could target employees and any individuals in close proximity to secured areas with ways to avoid risky behavior practices making individuals vulnerable to social engineering (Wilosinski, 2016). This could reduce the risk of the four types of social engineering attacks consisting of phishing, vishing, smishing, and exploiting social media accounts. This brings us to social media practices for employees so that employees keep personal social media accounts free of information tied to their workplace. The social media policy could create awareness for employees and other closely affiliated individuals to an organization to be cautious of information placed on public social networks due to risks of information used to create fake accounts asking colleagues for sensitive work information (Chen et al., 2017). The training could also include password policies that extend not to their work devices but also to their personal devices where work email is still accessible. This policy could encourage device-locking mechanisms on personal cellular phones (Bitton et al., 2018; Shaulov & Point, 2016). The training could also utilize device specific information to alert employees of vulnerabilities that affect their personal devices. For instance, Android users that elect to have a password pattern drawn by their finger for their personal device are at risk for that pattern being stolen if they leave their device unattended (Aviv et al., 2010). The training also could provide caution for wearable device technology users because this sector is advancing faster than subsequent laws, policies, and security systems and these devices could be hacked (Mills et al., 2016). Lastly, the training could provide a reminder of vulnerabilities with public wireless hotspots and the importance of not accessing sensitive information or using devices tied to work information while on these hotspots (Wilosinski, 2016).

Another security solution exists with malware. Malware detection has improved alongside the increase in malware prevalence. Research into malware detection mechanisms centers upon two predominant methods: dynamic analysis and static analysis (Tong & Yan, 2017). A static analysis consists of analyzing the application in question to determine if it has malicious code, without actually executing the application. This was identified as an acceptable initial screening indicator as to the nature of an application and its intended purpose. A dynamic analysis consists of analyzing the behavior of a particular application to see if the application in question is doing anything out of the ordinary. Another form of dynamic analysis, called an Android intent analysis, examines the intents, or requested permissions, by applications both explicit and implicit. According to Tong and Yan (2017), 97 % of malware programs, including but not limited to Trojans and viruses, target Android devices. Overall, organizations can help guard against security vulnerabilities through incorporating of better processes and technology.

3. Conclusion

Malware and hacking activities are growing amongst today's most popular mobile devices. These security risks are prompting organizations to enact policies aimed at mitigating the amount of espionage and illegal events that can transpire on a cell phone or other mobile device. The rise of cybercrime and cyberterrorism is not something that dwells in the realm of science-fiction novels, but exists in the real world, today, and is punishable by law (Cornell Law, Gathering, Transmitting or Losing Defense Information, 2012; Cornell Law, Gathering or Delivering Defense Information to Aid Foreign Government, 2012; Cornell Law, Disclosure of Classified Information, 2012). Pacini et al. (2008) suggests steps to preserve secrecy to include legal remedies and internal controls to protect trade secrets. Organizations can provide training to help safeguard against vulnerabilities by unsuspecting employees that could include topics such as avoiding risky behavior, social media practices, password practices, device specific vulnerabilities including cell phone brands and wearable devices, and public hotspot vulnerabilities. However, infected mobile device exposure is growing at an alarming rate, and Shaulov and Point (2016) report that, "on average, over one in 1,000 devices globally [are] infected," demonstrating the widespread proliferation of compromising methodologies (p. 5). Financial losses in 2014 reported more than $800 million due to scamming activities (Chen, Beaudoin, & Hong, 2017). The purpose of this literature review was to provide an overview of cell phone and electronic devices vulnerabilities, espionage in the workplace, and security solutions in the understanding of risks and threats in existence for cell phones and mobile devices. Future research is necessary to understand the threat of security infractions due to mobile devices within workplaces. Mobile devices continue to become more widely accepted while companies embrace BYOD programs but more research is necessary to lessen the gap in the research between academic and business aspects of information security (Silic & Back, 2014). Research focuses on attitudes and intentions with respect to information security policy with very limited studies on actual behavior necessitating the need for more research to identify interventions that reduce security vulnerabilities in the workplace (Sommestad et al., 2014).

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Safety Culture at a Collegiate Flight School

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Abstract

Safety management systems are implemented in aviation to assess and iteratively improve on safety, with the goal of monitoring and maintaining a strong safety culture to reduce risks and avoid future incidents and accidents. Maintaining a strong safety culture is a critical component of maintaining safety in organizations from airlines to flight schools. Safety management systems (SMSs) stress iterative assessment and improvement in order to decrease risk. Regular assessment of safety culture allows for the promotion of safety. The purpose of this study was to examine safety culture at a collegiate flight school in the southeastern United States using the Global Aviation Information Network's (GAIN) individual safety survey (2001) and determine if different groups within the organization had different perceptions of safety: undergraduate students in ground courses, maintenance personnel, and flight instructors. Overall, survey results indicated a positive safety culture. Although there was a significant difference in responses between students in Aeronautics 1 and 4, the effect size indicated that the difference was quite small, and there were no significant differences between any other groups.

1. Introduction

Wiegmann, Zhang, Von Tahaden, Sharma, and Gibbons (2004) summarized safety culture as a willingness to work as a group with each other regardless of ranks or titles. In aviation, building a strong organizational culture to promote safety is critical. This is often a part of SMSs in organizations, which include regular assessments to determine progress towards safety initiatives.

1.1. Purpose and significance

The purpose of this study was to examine the different perspectives of safety at a collegiate flight school in the southeastern United States. Using the GAIN (2001) safety survey, safety perceptions of undergraduate flight students, certified flight instructors (CFIs), and maintenance personnel were measured during the Fall 2018 semester. This survey methodology was selected to answer the research question: is there a difference in the safety perception of flight students, CFIs, and maintenance personnel?

Studying safety culture is important because part of a good safety culture involves evaluating and iteratively improving. Without regular, impartial assessment, this is impossible. While SMSs are not new in aviation organizations such as airlines and airports, flight school SMSs are relatively recent developments, and there is little research documenting this application of the SMS. This implementation of a previously established safety survey both provided a snapshot of safety perceptions at a collegiate flight program and allowed for comparison with industry standards for organizations (GAIN, 2001). The cross section of student experience level and various roles in the organization ensured a complete picture. To maintain a strong positive safety culture, methods for this type of internal analysis must be developed and regularly applied to evaluate the organization and ensure high standards of safety.

1.2. Safety management systems

As a high-risk, safety critical field, aviation has developed standardized approaches to minimize risk and continuously improve safety. SMSs are the official, organizational implementation of these goals (Cusick, Cortes, & Rodrigues, 2017). Reason's swiss cheese model argued that accidents are not just a result of a mistake but are also influenced by the organization's culture and policies as well as precursor actions (Cusick et al., 2017, Reason, 1990). Thus, avoiding accidents and incidents requires the active, standardized influence of the organization.

SMSs are founded on four main pillars: safety policy, risk management, safety assurance, and safety promotion (Cusick et al., 2017, FAA, 2010, Velazquez & Bier, 2015). The implementation requires organizational goals, solidified into a plan through company policies. Organizational commitment is key. The company must continually examine progress and efficiency of safety initiatives to reach its goals. This process in turn promotes an environment with a clear safety culture (Cusick et al., 2017).

1.3. Safety culture

Promoting safety includes safety training and the creation of a culture that reinforces the organization's goals and aims for risk management. Although there are a wide range of definitions of safety culture, Wiegmann et al. (2004) characterize several common threads. Safety culture includes a willingness of employees to work together no matter their position or level in the company. The group values regarding safety will influence actions, and a communal emphasis on standards and continual improvement builds safety culture. Additionally, there must be a willingness to learn and change (Wiegman et al., 2004). Although aviation is a safety critical field, this process of improvement and use of an SMS in improving safety has not been well documented in flight schools.

Safety surveys have been used in aviation to evaluate attitudes towards safety. Safety culture was assessed prior to and after the implementation of an SMS at Sharjah airport and compared to results at a sister airport. The results documented a positive change in safety culture with the SMS, while the safety scores at the control airport remained the same (Remawi, Bates, & Dix, 2011). SMSs have demonstrated value in building safety culture in aviation organizations and should have similar effects in flight schools.

In collegiate flight training, the development of safety culture can start from the first day with new flight students. However, the entire flight training program must be committed to the SMS and iterative safety improvement. Examining the safety culture through regular assessments, such as the GAIN (2001) safety survey, is a first step towards understanding safety culture in flight schools.

2. Methods

This study used a descriptive methodology, employing the GAIN safety survey to assess safety in an aviation organization and compare to other organizations. The safety survey was previously developed by GAIN (2001). Results from the survey allow comparison to safety culture benchmarks for organizations: "Poor safety culture 25-58, Bureaucratic safety culture 59-92, Positive safety culture 93-125" (GAIN, 2001, p. D-5). Demographic questions were appended to the safety survey to identify the participant's classification within the flight school: undergraduate flight student in Aeronautics 1-4, instructional techniques student, CFI, maintenance personnel, or non-flight student. An IRB exemption was approved (18-167) prior to initiation of research. Participation was voluntary and anonymous, and participants could opt out at any point. The survey posed minimal risk to participants.

Participants were recruited from the flight line (both maintenance employees and CFIs) and in all core aeronautics classes (Aeronautics 1-4 and Instructional Techniques) at a collegiate flight school in the southeastern United States. All employees and undergraduate students registered in ground courses were asked to participate. Paper copies of the surveys were distributed and collected in large envelopes, and then data were entered into an Excel spreadsheet. Descriptive statistics were conducted in Microsoft Excel; inferential statistics, including one-way ANOVA and eta squared, were calculated using RStudio v. 1.1.383.

3. Results

We collected a total of 202 surveys; of these, 45 were excluded from the analyses because they were from non-flight students or were missing responses on the second page (N=157). There were strong response rates from all three groups (Table 1): mechanics, CFIs, and undergraduate flight students.

Table 1. Sample Size and Response Rates for Safety Survey

Group	Sample	Population	Response Rate
Flight Students	129	229	56%
Certified Flight Instructors	21	31	68%
Maintenance	7	17	41%

Table 2 shows the descriptive statistics for safety scores by group. All measures of central tendency were in the positive safety culture range (93-125), except the mean safety score for Aeronautics 4 students. Aeronautics 4 had the largest range and standard deviation due to a single outlier. Flight instructors had the smallest safety score standard deviation. Average safety scores for all groups were similar (Figure 1).

Table 2. Safety Culture Score Descriptive Statistics at a Collegiate Flight Program

Group	Mean	Mode	Median	Range	Std. Dev.
Aeronautics 1	101.9	93	101	75-125	11.1
Aeronautics 2	97.7	103	96	75-113	10.5
Aeronautics 3	97.0	100.0	97	70-119	10.5
Aeronautics 4	91.6	96	97	47-112	16.8
Instructional Techniques	98.7	104	99	81-125	13.1
Certified Flight Instructor	101.9	101	130.5	84-115	8.5
Maintenance	105.8	NA	101	83-124	15.1

Groups examined included undergraduate flight students in core aeronautics courses (Aeronautics 1-4 and Instructional Techniques), certified flight instructors (CFIs), and maintenance personnel. Scores above the dashed target line (93) indicate a positive safety culture; scores between the dashed and dotted lines are bureaucratic; scores below the dotted line (58) indicate poor culture. Safety culture is defined as poor (25-58), bureaucratic (59-92), and positive (93-125) by GAIN (2001). Error bars represent one standard deviation above and below the mean.

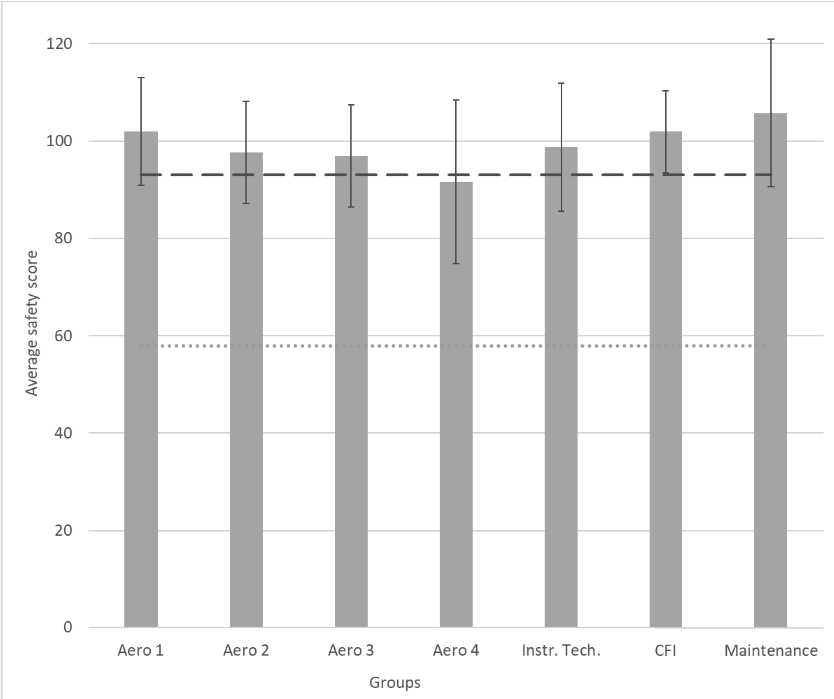

Figure 1: Safety Culture Scores by Group at a Collegiate Flight Program

There was a significant main effect for different groups, $F(6, 181) = 2.68$, $p = .01$. A post hoc, Tukey's pairwise comparison found that safety scores for Aeronautics 1 and 4 students were significantly different ($p = 0.03$); however, there was no significant difference between safety scores for all other groups. The eta squared was 0.08, which was a very small effect size.

4. Discussion

All certified flight instructors, maintenance personnel, and all flight students in the core aeronautics courses were asked to participate in the survey, generating an overall picture of safety at the collegiate flight program. These data illustrate perceptions of safety culture by all groups during that two-week period in the Fall 2018 semester when data were collected. The response rates were high (Table 1) and reasonable for voluntary participation via paper surveys, resulting in 157 surveys for the analysis. All groups were represented in the responses, including a cross section of flight student experience from new flight students in Aeronautics 1 to students training to be flight instructors in Instructional Techniques. Non-flight students were excluded because of their lower level of exposure to the flight line and SMS.

The GAIN safety survey is interpreted using the general categories for safety culture within organizations: safety culture scores from 25 to 58 indicating poor culture, 59 to 92 a bureaucratic culture, and 93-125 a positive culture (GAIN, 2001). The survey results documented a positive safety culture across all groups in the flight program, with the CFIs and maintenance employees having the highest average safety scores (Table 2, Figure 1). This may be due to their higher experience level and better understanding of the SMS. Aeronautics 1 had a high, positive safety score average as well, which could be because these flight students are new to aviation, and therefore eager to support the safety culture and follow proper safety procedures learned in class, from CFIs, and in the flight operations manual. The lowest average safety score was for Aeronautics 4 (91.6), which was at the high end of the bureaucratic safety culture category. We made the decision to include all completed responses from flight students and flight school employees, rather than excluding outliers, because all responses represent actual perceptions of safety culture at that point in time. However, the removal of the single Aeronautics 4 outlier would have increased the average safety score into the positive range (95).

Although there was a significant difference in safety scores between the Aeronautics 1 and 4 students, there was no difference between the other groups. The difference between Aeronautics 1 and 4 was likely driven by the outlier in the Aeronautics 4 responses. The miniscule effect size (0.08) also indicated that any differences in the perception of safety across the various groups at the flight school are negligible in the real world. This result is encouraging because all components of the organization have both a positive perception of the safety culture and a similar perception. Results indicating an overall bureaucratic safety culture point to an organization within which safety procedures are followed as rules or boxes to be checked rather than valuable safety practices. Likewise, different safety scores between groups serving different roles in the flight school might indicate concerning trends in the safety culture such as differing levels of emphasis on safety or unequal knowledge and understanding of the SMS between groups.

In conclusion, we found that the collegiate flight school has a positive safety culture across all groups. Best practices in safety management include continual assessment and improvement. As such, this survey assessment of safety culture should be regularly replicated at the flight school to examine trends in perceptions of safety over time and between various groups, so that any issues can be identified and addressed proactively. A comparative study of safety perception in Part 141 flight schools across the United States would be beneficial. Future research should also follow flight students in a longitudinal study of how perception of safety culture changes with pilot experience level within an organization.

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Examining Airline Ground Operation Incidents by Airport Size

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Abstract

Evaluating ground operations incidents is a critical step for airlines from both a management and safety perspective. Analysis of incidents is useful in both safety management and in planning for training and recurrent training of airline employees. De-identified data was provided by a major U.S. airline for all reported ground operations incidents from 2010-2017. This ex post facto research examined the rate of ground operations incidents by airport size for this airline, using both the National Plan of Integrated Airport Systems (NPIAS) classification and the airline's classification of airport size, based on its operations at each airport. NPIAS recognizes all commercial, reliever, and public airports in the national airport system, and the airports in this study were all classified as small/non-hub, or large/medium hub. The airline's size classification was based on its operations at a given airport and assigned airports as small, medium, large, or mega stations. The analysis of ground operations showed that the rate of incidents per operations did not differ with airport size for either the NPIAS size categories or the airline's size classification.

1. Introduction

Many incidents occur on the ground when aircraft are either taxiing or parked. The multitude of moving parts at airports, from fuel trucks, catering, and baggage carts to maintenance and security vehicles, combined with moving aircraft generates opportunities for mistakes. Studying these ground operations incidents is important from both a safety and business perspective. Likewise, understanding the rate of ground operation incidents per operation is critical for determining where to invest in safety improvements.

The purpose of this research was to investigate the relationship between the rate of ground operation incidents and airport size for a major U.S. airline from 2010 to 2017. Airport size was defined in two different ways: 1) the NPIAS airport size categories (FAA, 2019), and 2) the airline's station size categories based on its operations at each airport. The rate of ground operations incidents was calculated as the monthly ground operations incidents per airline operations at a given station.

This study provided information on the rate at which ground operations incidents occurred at various airports by airport size for a major U.S. airline. Any relationship between airline ground operations incidents and airport size can be used to develop safety practices that minimize incidents, whether this includes changes to the airport design and environment, new procedures, and/or recurrent training for employees. The analysis of existing organizational data on ground incidents to understand patterns and potential causes is a challenge for airlines (Wenner & Drury, 2000). Determining a baseline of ground operations incidents by airport size would help move towards improving safety for passengers and minimizing the impact of incidents on airlines' operating costs.

2. Ground operations incidents

Airports are complex environments with many moving parts that, while regulated, require the participation of various entities from pilots and ground crew to air traffic control and airport management. Safety in such complex systems requires a system approach involving all stakeholders (Wilke, Majumdar, & Ochieng, 2014).

Although accidents are well studied in aviation, the literature contains relatively few examples of research on airline ground operations incidents. There are at least two estimates of the frequency of ground incidents: a) "the figures range from 2.7 to 7.2 incidences per 10,000 departures" (Matthews, 2000, p. 4) and b) "100-200 reportable GDIs [ground damage incidents] each year" (Wenner & Drury, 2000, p. 178) at an airline. Wenner and Drury (1996, 2000) analyzed 130 ground operations incidents from an airline in order to determine typical patterns and types of ground operations incidents. Their analysis categorized the events into towing/taxiing, and parked incidents from either another object or vehicle striking the aircraft or the aircraft moving to contact an object or vehicle. These three main types of incidents accounted for 94% of the damage events studied (Wenner & Drury, 2000). However, this research spanned three years at a single airline and did not specify the number of operations.

Wilke, Majumdar, and Ochieng (2015) examined airport surface accidents in relationship to the airports' characteristics. While this study focused on more severe accidents (not incidents), and on runway related events in particular, the conclusion was that the airport design, specifically complexity, served as a predictor of severity in events (Wilke et al., 2015). Thus, airport characteristics warrant further study in relation to ground operations.

In addition to the obvious safety impacts, ground operations incidents are important in aviation because of their large costs. Aircraft repairs and damaged equipment are some of the direct or tangible costs associated with ground operations incidents. However, indirect, or latent costs, such as delays, disrupted travel, consumer perceptions, and aircraft time out of service (lost profit), must also be accounted for but are much more challenging to quantify (Matthews, 2000; Wenner & Drury, 2000). Matthews (2000) estimated an annual global cost of three billion dollars, when accounting for both direct and indirect costs. While the costs are high, these events are often preventable (Matthews, 2000; Wenner & Drury, 2000), and manageable (Matthews, 2000), indicating this is an area with potential research impacts, as well as a focal point for safety management efforts.

In order to minimize the costs from ground operations incidents for airlines and maximize the safety for airline passengers and employees, research on the actual rates of ground operations incidents is critical. Understanding how the rate of incidents varies with airport size will aid in planning to these ends. This study addressed the question of whether there is a difference in the rate of ground operations incidents per operations at a major U.S. airline using both the NPIAS (FAA, 2019) and airline's airport size classifications.

3. Methodology

The methodology used for this research was an ex-post facto design. The data were received from a major U.S. airline and included all of the airline's archived data on ground operation incidents in the U.S. between January 1, 2010 and June 30, 2017. The data were deidentified with three letter airport identifiers re-coded to randomly assigned numbers, and aircraft tail numbers and employee names removed. The IRB exemption was approved (17-136) and included confidentiality, ensuring that the data were deidentified, presenting the data in in aggregate, and storing the data on password protected devices.

After the deidentified data was received from the airline, unknown stations that did not have an airline size classification were removed from the dataset. The dataset contained 84 stations and a total of 5,497 incidents during the 7.5 years examined.

The NPIAS size classification (Table 1) and the airline's size classification (Table 2) were used as categorical size variables for airports. The rate of ground operations incidents was calculated as the number of incidents per month divided by the number of operations (flights) that the airline conducted at the airport. Results were reports as number of incidents per 10,000 operations. Descriptive statistics were calculated in Microsoft Excel. Inferential statistics were calculated in RStudio v.1.1.383. An independent t-test was used for the NPIAS classification of airport size, and a one-way ANOVA was conducted for the airline classification.

Table 1. NPIAS airport classification by boardings that are continuations

NPIAS Size	Boardings/Year	Percentage of boardings
Nonhub primary or Small Hub	at least 2,500 to more than 10,000	at least 2,500 to 0.24%
Medium Hub	More than 10,000	at least 0.25%
Large Hub	More than 10,000	1% or more

Note. Group 1 includes both Non-hub and Small hub airports; group 2 (gray shading) includes medium and large hubs. Adapted from FAA (2019).

Table 2. Airline station size classification by number of operations at airport

Station Size	Mean Daily Ops.	Mean Weekly Ops.
Small	9.3	65
Medium	38.8	272
Large	72.7	509
Mega	159.6	1117

4. Results

The deidentified data file of ground operations incidents received from the major U.S. airline contained 5,497 incidents over a 7.5-year period from 2010 to 2017. For the purpose of this research, 3,039 incidents were missing information on the ground incident, specifically the location of the incident. Therefore, these incidents were excluded from analyses. There were 84 stations with incidents that were included in the analyses. All of the stations were associated with a NPIAS airport size classification (Table 1) as well as an airline airport (station) size classification (Table 2), based on the airline's number of operations at each airport.

Overall, the average incident rates were low, in the range of two to four ground operation incidents per 10,000 flights. For the NPIAS classification, the sample size was 32 airports in the Small or non-hub category and 52 stations in the large or medium hub category. Table 3 shows the descriptive statistics for ground operations incidents per 10,000 operations by NPIAS classification of airport size. The average rate of incidents for small and non-hub airports was 2.8 per 10,000 operations, while the rate for large and medium hubs was 4.3 per 10,000 operations, almost two times the average rate at small/ non-hub airports. There was a larger range for ground operations incident rates at large and medium hubs in comparison to small and non-hub airports. This larger standard deviation for large and medium hubs is reflected in both Table 3 and Figure 1 (error bars) and overlapped the distribution of rates at small/non-hub airports.

Table 3: Descriptive statistics for the rate of ground operations incidents per 10,000 operations by NPIAS airport size

NPIAS Size	Mean	Median	Mode	Std. Deviation	Minimum	Maximum
Small/Non-hub	2.8	2.7	4.3	1.6	0.6	7.1
Large/Medium Hub	4.3	2.6	NA	10.4	0.9	76.9

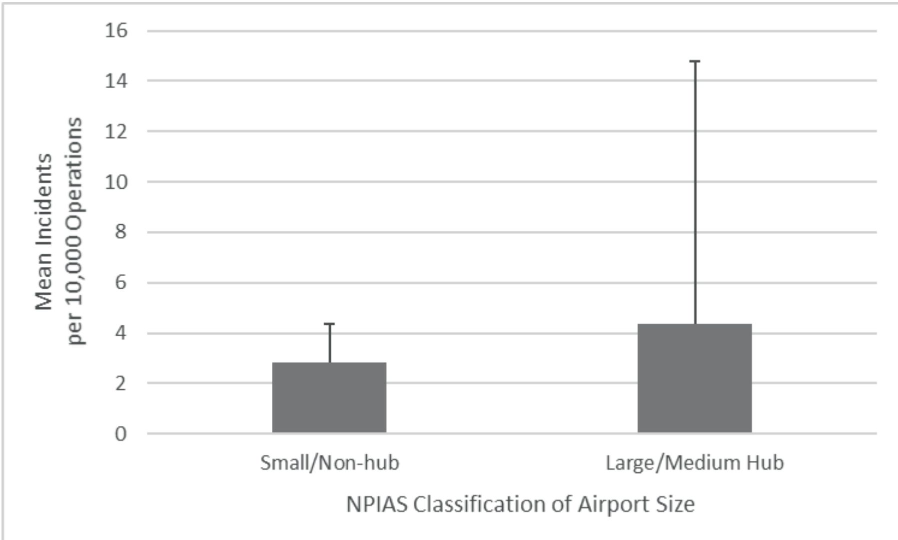

Figure 1. Ground operations incidents per 10,000 operations by NPIAS classification.
The rate of incidents is the average number of monthly incidents per operations at an airport averaged by NPIAS airport size category, and then reported as incidents per 10,000 operations. Error bars represent one standard deviation.

Descriptive statistics for ground operations by airline size category (Table 2) also indicated low rates of incidents, between 1.6 and 4.7 incidents per 10,000 operations, and the rates were consistent across the medium, large, and mega size categories (Table 4). The highest average rate of ground operation incidents occurred at small airport stations, and the large stations had slightly lower average rates of incidents than other sizes. The small stations also had the largest standard deviation (Table 4, Figure 2). A mode was only found for the small station category.

Table 4. Descriptive statistics for the rate of ground operations incidents per 10,000 operations by airline size classification

Airport Size	Mean	Median	Mode	Std. Deviation	Minimum	Maximum
Small	4.7	3.1	4.3	10.7	0.6	76.9
Medium	2.8	2.6	NA	1.0	1.0	4.3
Large	1.6	1.6	NA	0.5	1.1	2.6
Mega	2.5	2.6	NA	0.6	1.3	3.3

The major U.S. airline classified stations by size, using the number of operations conducted at each airport. The rate of ground operations was calculated as monthly incidents divided by the monthly operations at each airport, and then reported as incidents per 10,000 operations.

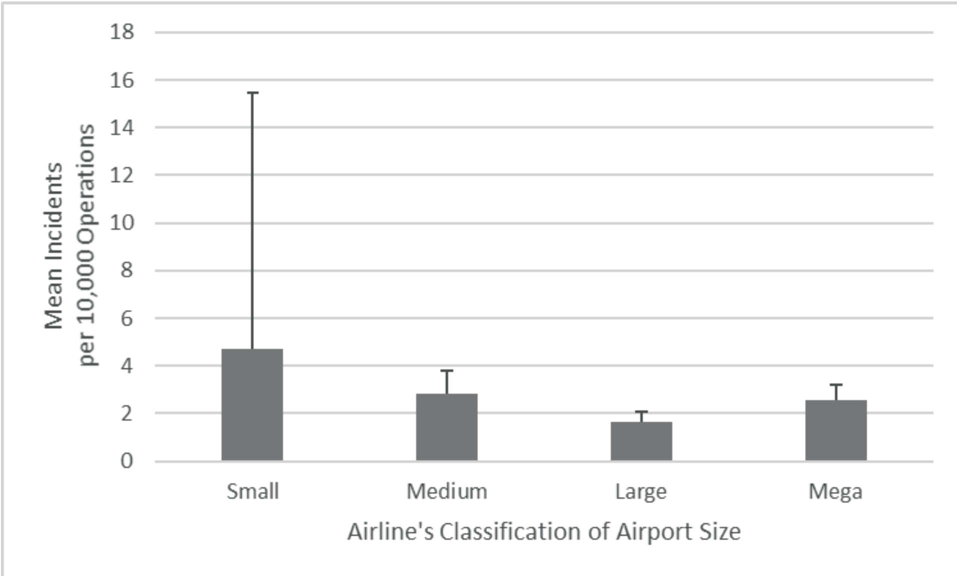

Figure 2. Ground operations incidents per 10,000 operations by airline classification.
The rate of incidents is the average number of monthly incidents per operations at an airport averaged by airport size category, and then reported as incidents per 10,000 operations. Error bars are one standard deviation.

The inferential statistics demonstrated that there were no significant differences in rate of ground operations by airport size, regardless of the size categorization used. An independent t-test showed that there was no significant difference in rate of ground operations incidents between NPIAS size classes: t (84) = 1.05, df = 54.7, p = .3. Cohen's d indicated a small effect size (0.2). A one-way ANOVA found no significant difference in rate of ground operations incidents by the airline's size classification: F (3, 80) = 0.06, p = .64. The eta squared was 0.02, which is a negligible effect size.

5. Discussion

The average incidents per operations for large and medium sized hubs (2.8 per 10,000 operations) and small and non-hub airports (4.3 per 10,000 operations) were relatively low rates and not significantly different (p= .3). The rates of ground operations incidents by airline size classification were also not significantly different (p= .64). The small effect sizes indicate that there is no practical difference in the rate of ground operations incidents with airport size.

The ground operations incident rates (1.6 to 4.7 incidents per 10,000 operations) were overlapping the range estimated by Matthews (2000), although slightly lower than Matthews' estimate of 2.7 to 7.2 per 10,000. The results were contrary to the initial hypothesis that larger airports would have higher rates of incidents. However, the support for the null hypothesis is promising from both a business and safety perspective: there is no airport size category that has a greater frequency of ground incidents. This is interesting because airport design varies, and often larger airports have more complicated designs that might introduce opportunities for mistakes and incidents.

Ex post facto research has inherent limitations because when using archival data the researcher has no control over data collection. Thus, reports with missing information, in this case the location field for where airport damage occurred, necessarily must be excluded. We were unable to use incidents if there was no location given. It is possible that the results would change, if there were access to location data for more of the incidents.

The largest variation in frequency of ground operations incidents occurred in the large/medium hub airports in the NPIAS classification but in the small station category of the airline's size classification. This is possible because an airline could have a small number of operations at a large hub airport, or alternatively, a large number of operations (mega airline category) at a small hub airport. Thus, a given airport may fall into different size categories in the two classification systems. However, examination of both methods of defining airport size is important to understanding ground operations. Further study of stations with higher variations in frequency of ground operations incidents is warranted.

This study examined the ground operations incidents at all U.S. stations of a major U.S. airline over a period of 7.5 years and concluded that there was no difference in rate of incidents between airports of different sizes as classified with either NPIAS or airline size categories. This is a positive outcome from the perspective that it suggests the airline does not have an issue with ground operations at a particular size of airport. Future research should compare trends in ground operations incidents for the airline over time, and if data is available, compare ground operations incidents between multiple airlines. Other avenues of inquiry include examining which specific stations have the highest rates of ground operations incidents, as these stations may need extra recurrent training to minimize risk.

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Operational Mishap and Incident Reports by Phase of Flight

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Abstract

Voluntary reporting programs such as the Aviation Safety Action Program and Aviation Safety Reporting System exist so that organizations are able to detect problems, trends, and hazards during flight operations and make iterative improvements, constituting proactive safety management. Reporting systems are an integral component of safety management systems for flight schools. Understanding the difference in mishap frequency by phase of flight will help the aviation industry become more aware of when errors are occurring during flight training. This study examined the Operational Mishap and Incident Reports (OMIRs) from a collegiate flight program in the southeastern United States. De-identified data from the OMIRs for 2015-2017 were provided for the study. All reports were classified into seven phases of flight: ground-parked, ground-moving, takeoff and climb, cruise, maneuvers, pattern operations, and descent and landing. There was a significant difference in the frequency of OMIRs by phase of flight. Ground phases, both parked and taxiing, had the highest frequency of reports, followed by descent and landing.

1. Introduction

Voluntary incident reporting aims to identify variables that may lead to incidents and accidents in order to make corrective actions for future safety (Runciman, 2001). Given that approximately 34% of all general aviation accidents occur during flight training, and around 95% of those incidents are due to human error (Houston, 2012), the identification of mistakes and patterns of error during flight training through voluntary reporting has potential for a powerful effect on safety in aviation.

The purpose of this study was to determine whether there was a difference in the frequency of OMIRs by phase of flight at a collegiate flight school in the southeastern United States. Phase of flight was classified into seven phases: ground parked, ground moving, takeoff and climb, cruise, maneuvers, pattern operations, and descent and landing. The flight school provided archival data from all OMIRs submitted from January 2015 to December 2017 in the flight school's safety management system (SMS).

Research and awareness is critical to promoting a safer flight-training environment for student pilots and instructors (Houston, 2012). Safety management systems are uncommon at collegiate flight schools. Thus, access to OMIRs provided a unique opportunity to learn about where errors are occurring in flight training. Understanding the variation in incidents and mishaps by phase of flight during flight training can be used to improve awareness for student pilots and flight instructors by highlighting specific phases of flight that incur more OMIRs. This could be the first step in identifying how to reduce the potential for mistakes and incidents that warrant a report. In addition, developing a plan to help reduce the potential of future mishaps will help lead the industry towards a safer flight environment.

This research was limited by the nature of voluntary reporting: it is possible that not all mishaps and incidents were reported. However, the SMS has built in incentives for reporting to increase participation, including immunity for pilots. It is also possible that some situations that warranted a report did not result in an OMIR because the pilot was not aware that the event should be reported through an OMIR. That said, the reporting system was introduced to all new student pilots, and flight instructors help teach new students about the system. Therefore, pilots at the flight school should be aware of the reporting system, when it is appropriate to submit a report, and the benefits to participating in the voluntary reporting system.

1.1. Aviation voluntary reporting systems

Although most aviation accidents have been attributed to human factors (NTSB, 2010), accidents, incidents, and lower-level errors or mishaps can be viewed from either an individual or system approach. The individual perspective focuses on mistakes, potentially caused by fatigue, task overload, or lack of attention. However, the system perspective emphasizes the role of the organization and environment in protecting against mistakes (Reason, 2000). From the organizational perspective, developing a positive culture of safety management is critical, and a central part of this is reporting mistakes so that learning can occur, rather than blame (Reason, 2000).

The aim of voluntary reporting in aviation is the ability to learn from more common small errors, in order to improve safety and avoid more severe accidents. Effective reporting systems in fields from aviation to medicine can enable learning through four essential functions: 1) gathering data that feeds into learning and safety culture rather than punishment or disciplinary action; 2) collecting complete data with closed and open questions; 3) implementing data analysis to translate reports into safety outcomes; and 4) providing constructive rather than critical feedback (Majahjan, 2010). Reporting systems need buy-in from everyone to function well (Majahjan, 2010; Runciman, Merry, & Smith, 2001). To increase participation, anonymity of reports allows for participation without fear of negative career impacts and increases the ability to collect data about causal reasons for errors (Runciman et al., 2001). Alternatively, reporting systems may incentivize participation by offering immunity or partial immunity in exchange for reporting and submission to any training deemed necessary. Regardless of the method, maximizing participation in a reporting system is critical to its effectiveness as a tool to learn from mistakes and proactively manage risk.

In aviation, several reporting systems exist. The Federal Aviation Administration (FAA) established the Aviation Safety Action Program (ASAP) to create voluntary reporting systems through safety partnerships between the FAA and businesses. For example, airlines and unions work with the FAA to promote confidential reporting of unsafe situations or occurrences. While not anonymous, some level of protection from punitive action and confidentiality serves to increase participation. The National Aeronautics and Space Administration (NASA) has oversight of the Aviation Safety Reporting System (ASRS) for the FAA, in order for the FAA, as the regulating agency, to maintain distance from the program. ASRS aims to support human factors research to identify issues and improve safety, is publicly accessible, and accepts submissions from anyone who witnesses a safety incident (e.g. air traffic controllers, pilots, maintenance, flight attendance). One of the central elements is confidentiality and anonymity provided by removing identifiers from data when it becomes part of the database and protection for pilots who submit reports (Cusick, Cortes, & Rodrigues, 2017).

Within organizations, developing a safety culture that places value on voluntary reporting is a central component to a safety management system. Although safety management systems are a recent development at collegiate flight programs, voluntary reporting enables identification of safety issues and iterative improvement. At the collegiate flight program in this study, a voluntary reporting system of OMIRs is used to collect data on safety-related events. This also serves to ensure that everyone involved in the flight program has an outlet to be heard, increasing participation and engagement (Runciman et al., 2001). The OMIRs may be submitted by anyone and serve as the interface to the outside reporting system, ASAP. Therefore, the reports also offer pilots performing operations for the primary business of the flight school immunity, a further incentive for participation. Collection of voluntary reports through the SMS also enables monitoring and safety research.

1.2. Phases of flight

The FAA (2016) breaks flight operations into nine phases of flight: preflight/taxi, takeoff, climb, cruise, descent, maneuvering, approach, landing, and other. While climb, cruise, and descent phases comprise 83% of flight time, only approximately 21.6% of general aviation accidents occur during these phases. In contrast, takeoff and initial climb represent only two percent of flight time but 23% of accidents, and 24% of accidents occur during landing (FAA, 2016). Thus, the takeoff and landing phases of flight alone account for approximately half of the accidents in general aviation.

Pilots are trained to anticipate workload and manage their workload. However, during a given flight, the approach and landing phase is when the pilot workload is highest. Pilots may reach task saturation, which means the workload may exceed the lowest margin of safety (FAA, 2016). This is one reason that a higher percentage of accidents occur during landing: the high workload may result in more human errors.

While the general aviation accident risk is highest in the takeoff and landing phases of flight (FAA, 2016), research is necessary to determine the incidence of mistakes by phase of flight during flight training. The voluntary reporting system consisting of OMIRs at a collegiate flight school provided the means to quantify and explore the differences in mistakes between phases of flight.

2. Methods

We used an ex post facto methodology in order to compare the frequency of OMIRs by phase of flight. An Institutional Review Board exemption (18-168) was approved. Deidentified data maintained the anonymity of individuals who submitted reports, and the study used archival data, having no direct contact with human subjects. The flight school provided de-identified data files, containing all OMIRs submitted from January 2015 through December 2017, or three full calendar years.

The flight phase column in the reports was used as the initial classification of phase of flight. Full reports and descriptions were used to code the 18 different phases of flight found in the dataset into seven categories: (a) ground parked, (b) ground moving, (c) takeoff and climb, (d) cruise, (e) maneuvers, (f) pattern operations, and (g) descent and landing. These categories align closely with the FAA (2016) phases of flight; however, parked and taxiing ground phases were separated, and takeoff and climb were combined. The number of OMIRs for each phase of flight was tallied by month (36 months). Descriptive statistics were calculated in Microsoft Excel. RStudio version 1.1.383 was used to calculate a one-way Analysis of Variance (ANOVA), Tukey’s pairwise comparison, and effect size.

3. Results

A total of 689 OMIRs were provided in the archival data; Table 1 shows the breakdown of OMIRs by year and by total flight hours at the flight school. This represents an average reporting rate of approximately one OMIR per 70 flight hours. A total of 18 OMIRs were excluded because the phase of flight was unknown or unclear from the report, resulting in 671 OMIRs that were used for the analyses. Figure 1 and Table 2 depict the 671 total OMIRs by phase of flight. Ground parked had the highest frequency of reports (177), followed by ground-moving (163) and descent and landing (115). The two ground phases together accounted for just over half of the total reports. The other five phases had fewer reports, with the fewest reports during maneuvers (38). Ground parked had the highest standard deviation (3.5), and maneuvers and cruise had the lowest standard deviations (1.1). Figure 2 depicts the average monthly OMIRs submitted by phase of flight with the standard deviation overlaid.

Table 1. Operational Mishaps and Incident Reports and Flight Hours by Year

Year	OMIRs Submitted	Flight Hours
2015	259	14866
2016	231	17082
2017	199	15303
Total	689	47251

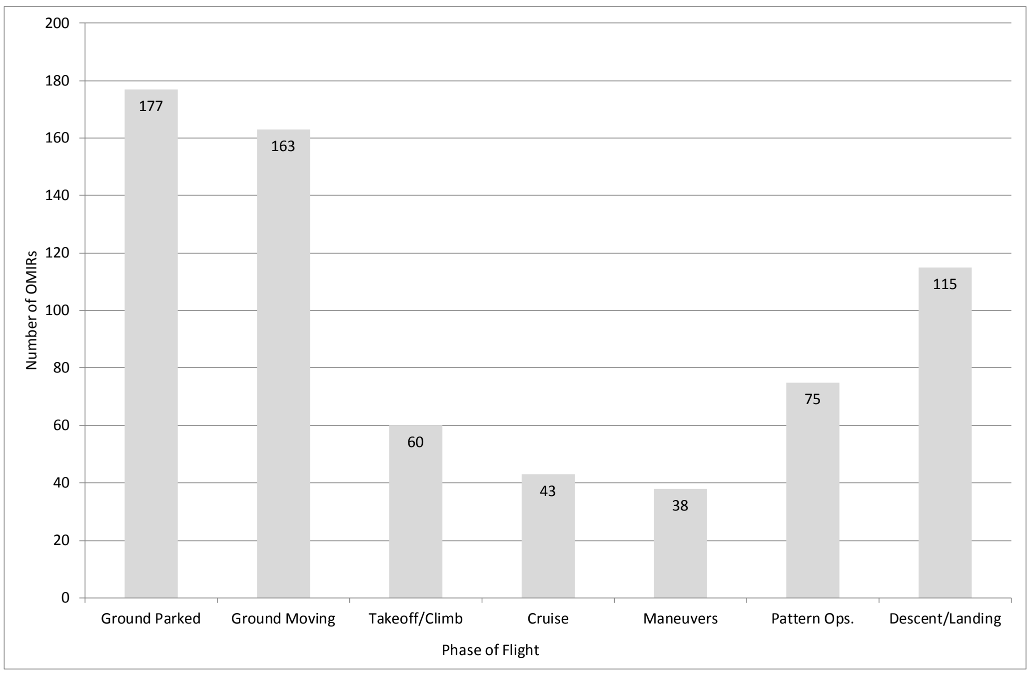

Figure 1. Operational Mishaps and Incident Reports by Phase of Flight

Table 2. Descriptive statistics for Operational Mishaps and Incident Reports by phase of flight

Phase	Total OMIRs	Mean	Mode	Median	Range	Std. Deviation
Ground Parked	177	4.9	4	4	15	3.5
Ground Moving	163	4.5	3	5	10	3.0
Takeoff/Climb	60	1.7	0	1.5	6	1.7
Cruise	43	1.2	1	1	4	1.1
Maneuvers	38	1.1	1	1	4	1.1
Pattern Ops.	75	2.1	0	2	6	1.7
Descent/Landing	115	3.2	2	3	8	2.4

Mean OMIRs are the average number of reports per month in each phase of flight from 2015 through 2017. Statistics were calculated on monthly tallies of reports by phase of flight.

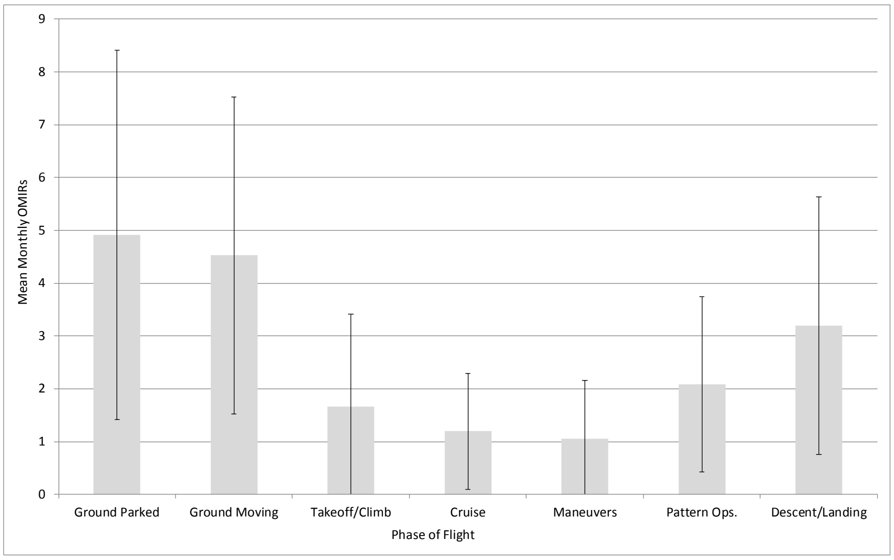

Figure 2. Operational Mishaps and Incident Reports by Phase of Flight

Average monthly OMIRs are reported by phase of flight. Error bars represent a standard deviation above and below the mean.

Table 3. Tukey's Pairwise Comparison of OMIR Rate by Phase of Flight

Phases compared	*p*
Ground Parked & Takeoff/Climb	< 0.001
Ground Parked & Cruise	< 0.001
Ground Parked & Maneuvers	< 0.001
Ground Parked & Pattern Ops	< 0.001
Ground Parked & Descent/Landing	0.02
Ground Moving & Takeoff/Climb	< 0.001
Ground Moving & Cruise	< 0.001
Ground Moving & Maneuvers	< 0.001
Ground Moving & Pattern Ops.	< 0.001
Descent/Landing & Maneuvers	0.001
Descent/Landing & Cruise	0.004

Note: Only pairwise comparisons with significant *p* values ($p < 0.05$) are shown; all other pairs were not statistically different.

The ANOVA found a significant effect for phase of flight: $F(6, 245) = 17.65$, $p < .01$. To determine which phases of flight had different OMIR frequencies, a post hoc analysis was necessary. Tukey's pairwise comparison showed that 11 pairs of phases of flight had different OMIR frequencies at $p < .02$ (Table 3). Ground parked and ground moving were not different from each other, but were different from other phases: takeoff and climb, pattern operations, maneuvers, and cruise. Descent and landing was different from cruise and maneuvers. The eta-squared was 0.302, which is a small effect size.

4. Discussion

The data on OMIR frequency by month supported the hypothesis that there would be a difference in the frequency of reporting by phase of flight. As illustrated in Tables 2 and 3 and Figure 2, there is a difference in voluntary reporting based on phase of flight. The frequencies of OMIRs from the ground parked and the ground moving phases were significantly higher than other phases of flight, except descent and landing. Descent and landing had a higher frequency than cruise and maneuvering. However, the effect size (eta squared= 0.302) was small, suggesting that even though there is a statistical difference, the difference in the real world is small.

The difference in voluntary reporting underscores the higher frequencies during the ground parked and ground moving phases, which approximately half of the OMIRs referenced. There are several reasons that this may be the case. First, while still on the ground, the preflight examination of the aircraft and startup procedures have checklists, creating a multitude of potential mishaps if they are not properly completed. Second, while all operations necessarily include some phases of flight (e.g. ground parked, ground moving, takeoff and landing), not all flights will include every phase. Third, a self-report by a flight student or a report by a flight instructor would be most common for OMIRs during flight. However, on the ground, there are other people at the flight line that may observe an unsafe event and submit an OMIR, introducing the potential for more reports made by observers. Anyone can submit a report, and there are more observers on the ground.

Descent and landing was also significantly higher than cruise and maneuvering. Again, while almost all flights involve ramp or taxi phase and landing phase, not all operations have a cruise or maneuver phase, depending on the aims of a particular flight lesson. While parked and taxing reports were the most common, all flights involve a landing phase, and this is a heavy workload phase of flight for the pilot, introducing potential for mistakes, as compared to cruise and maneuvers, which are more straightforward and require a lower pilot workload.

When interpreting these results, the number or frequency of OMIRs should not be equated with risk. That is, even though the ground parked and ground moving phases had the highest OMIR frequencies, other phases of flight may have the higher risks. One cannot automatically assume that a higher number of reports is the result of a higher risk level in a specific flight phase.

Future research should evaluate trends in voluntary reporting over time. Elements such as number of daily operations at the flight line and airspace category should also be examined for their impact on frequency of reports. Finally, research relating the severity of the incident or potential risk with OMIR frequency would help to further understand these relationships and risks.

Voluntary incident reporting enables the aviation industry to proactively identify issues to improve safety. Analyzing OMIRs at collegiate flight training programs increases understanding of which phases of flight have more incidents and mishaps: ground parked, ground moving, and descent and landing. This, in turn, can be used by flight instructors to improve training. However, a higher frequency of reports in a specific phase does not necessarily mean that there is a higher associated level of risk.

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