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Assessment of Effectiveness of Teamwork Skills Learning in Collaborative Learning

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Abstract

The article gives the historical background and current status of the collaborative learning in higher learning institutions. By exploring the collaborative and cooperative modes of learning the article points out the similarities and differences between them. A theme of learning styles and its significance is revisited. A collaborative learning in engineering education is analyzed and followed by a description of methodologies employed by engineering and engineering technology programs. As teamwork skills play a vital and often determining factor in any successful collaborative activity the article provides an example of an assessment method employed to check the effectiveness of learning the teamwork attributes in the engineering and science sophomore course. The article assesses the learning effectiveness of teamwork attributes using hypotheses testing based on student self-evaluation.

1. Introduction: Historical Background of Collaborative Learning

Collaboration and cooperative activities are as old as humanity itself. Actions taken among collaborating persons allowed groups to survive. This led to the rise of civilizations and the architectural and civil engineering marvels of antiquity and present day. So it is not surprising that the collaborative type of activity found its way into education. As Johnson and Johnson (2017) wrote, already in the seventeen century Johann Amos Comenius "believed that students would benefit both by teaching and being taught by other students." In the last fifty years or so there was an increasing conviction among researchers supported by empirical evidence that collaborative activities in learning and teaching processes offer improvements in attaining planned learning outcomes over traditional passive and competitive learning environments. Johnson and Johnson (2017) refer to over 375 studies conducted in the past 90 years which show that "working together to achieve a common goal produces higher achievement and greater productivity than does working alone." Thus active, collaborative learning environments offer, as these empirical studies suggest, an improvement in learning outcomes as compared to more traditional passive and competitive or individualistic learning settings. The educational changes initiated by academia in the last few decades went further and included crossing disciplinary barriers (Bordogna and Ernst, 1993; Miller and Olds, 1992; among others) and a refocus on soft or "socio-engineering" skills (Augustine, 1994; among others).

Naturally, there were other factors at play outside of academia that prompted universities to look at improving the effectiveness and efficiencies of teaching and learning processes. Budgetary constraints mainly due to diminishing state support for higher learning institutions as reported already in the 1990s (Meade, 1991; Major, 1994) has only deepened in the recent decade. On average, U.S. states have not returned to pre-crisis of 2008 expenditures for higher education (Center on Budget and Policy Priorities, www.cbpp.org). Mitchell et al. (2017) reported that "states cut funding deeply after the recession hit. The average state spent $1,448, or 16 percent, less per student in 2017 than in 2008." While only a few states such as Indiana, Montana, Nebraska, North Dakota, and Wyoming, according to the report, increased expenditures compared to 2008, "per-student funding in eight states — Alabama, Arizona,

Illinois, Louisiana, New Mexico, Oklahoma, Pennsylvania, and South Carolina — fell by more than 30 percent over this period." (Mitchell et al., 2017)

Higher learning institutions are turning to new ways of delivering courses that would improve overall efficiencies and retention. The issue of retention is an important one considering the fact that while up to 1995, around 20 percent of the USA population held at least a 4-year academic degree; in 2010, that number reached 30 percent. According to the USA National Center for Educational Statistics the percentage of 18- to 24-year-olds enrolled in college and university was 35.5 percent in 2000 and 40.5 percent in 2015. Thus, a larger and larger portion of eligible members of society, traditional high-school graduates, but also an increasing number of non-traditional working adults enrolled at colleges with many who lack necessary skills for success. Weismann (2014) reported graduation rates of 59 percent for traditional students and 40 percent for older students as of 2008. The reported high attrition rates (Smith and MacGregor, 1992; Weismann, 2014) made colleges realize that more students need assistance to improve their study skills and academic aptitudes, which are critically important to overall academic success. Emotional isolation and passivity, which were observed in student cohorts are other factors that traditional education was poorly equipped to deal with. In addition to these issues, the nation will face a shortage of skilled workers. The Bill and Melinda Gates Foundation (2018) writes "unless we dramatically improve student success in higher education, our nation will suffer from a shortage of skilled workers needed to ensure global competitiveness and national security. We are currently on track to produce at least 11 million fewer career-relevant certificates and degrees than our economy will require by 2025."

Thus, academia realized that new ways of teaching and learning were needed to address these pressing issues (Levine and Weingart, 1973; among others). Collaborative learning offered a hope to tackle the listed above shortcomings and to improve learning outcomes.

In the next section a brief history of collaborative learning with current trends and the differences between collaborative and cooperative learning are provided, followed by a review of collaborative learning in engineering with an assessment of the learning process of teamwork attributes.

2. Collaborative Learning: Status and Trends

In this section the collaborative learning's origin, status and trends, and the differences between collaborative and cooperative learning are provided and analyzed.

2.1 Collaborative Learning

Collaborative learning is a term which covers a variety of educational approaches where students work together to achieve educational objectives under an instructor's guidance or supervision. According to Bruffee (1984), the term "collaborative learning" was coined by British teachers in the 1950s involved in a ten-year research study of medical students performed at University College, University of London suggesting that diagnosis as "the key element of any successful medical practice is better learned in small groups of students arriving at diagnoses collaboratively than it is learned by students working individually." Furthermore, Bruffee (1984) points out that the origin of implementing collaborative learning at the college level "lies neither in radical politics nor research." The roots lie, Bruffee (1984) writes, in "the nearly desperate response of harried colleges" to address "[the] pressing educational need" in which increasingly students had "difficulty of doing well in college studies" and "adapting to the traditional conventions of [the] college classroom."

Smith and MacGregor (1992) wrote "collaborative learning represents a significant shift away from the typical teacher-centered or lecture-centered milieu in college." It encompasses a variety of pedagogical methods which submerge students directly in their education process through engagements in active learning through working with others to achieve common goals. In traditional

learning the focus is on individual performance – low level of interdependence, teamwork skills are essentially ignored, learning engagement with others is limited, and the reward system is tailored toward individual success (MacGregor, 1992; Smith, 1986; Jonson and Johnson, 2013). In collaborative learning, on other hand, a positive interdependence is needed, communication, social and team-work skills are expected, and both individual and group accountability play important roles in educational tasks (MacGregor, 1992; Smith, 1986; Smith, Johnson and Johnson, 1992; Johnson and Johnson, 2013, 2017; McCown, 1994). Authors (MacGregor, 1992; McCown, 1994; Smith, 1986) point out the differences between traditional and collaborative or cooperative learning groups with respect to level of interdependence, accountability, responsibility for individual and group learning progress, level of application of teamwork skills, and group processing in attaining learning objectives. Usually, cooperative learning provides a more structured setting with precisely defined roles, expectations, and time schedule with deadlines in comparison to collaborative learning.

Although the concept of a *group* is used interchangeably with a *team* in the literature dedicated to collaborative learning, here it is assumed that a team is a more formally formed structured group often with an imposed, non-volunteer based membership with a specific objective and time frame for achieving it.

2.2 Collaborative vs. Cooperative Learning

Although the concept of collaborative learning has been and still is used equivalently and synonymously with cooperative learning, the two concepts do differ. In both approaches the educational goal is to facilitate learning by "changing students from passive recipients of information given by an expert teacher to active participants in the construction of knowledge" (Goodsell et al., 1992). The two approaches differ "according to the amount of structure provided for students and the degree of constructed knowledge presented" (Goodsell et al., 1992). Both methods encompass a variety of learning and teaching methods and strategies. Collaborative learning, as Smith and MacGregor wrote in Goodsell et al. (1992) is "an umbrella term for a variety of educational approaches involving intellectual effort by students, or students and teachers together." In this approach "students are working in groups of two or more, mutually searching for understanding, solutions, or meaning, or creating a product" (Goodsell et al. 1992). In cooperative learning, by comparison, the learning is much more structured. As Smith and MacGregor wrote in Goodsell et al. (1992) "cooperative learning structures group learning around precisely defined tasks or problems." Johnson, Johnson and Smith (2014) point to the social interdependence theory for laying the foundation of cooperative learning. They credited work by Koffka, Lewin, and Deutsch (1949) of the early 1900s to the study of interdependence among group members affecting cooperation and competition, and their mutual impacts for providing theoretical foundations and rationale for cooperative learning. According to Johnson and Johnson (2005) cooperative learning is a pedagogical method where "students work together to maximize their own and each other's learning." Smith and MacGregor (1992) and Johnson and Johnson (2017) stipulated that cooperative learning have five essential elements:

- positive interdependence,
- promotive interaction,
- individual accountability and personal responsibility,
- social skills, and
- group processing.

Positive interdependence, according to Johnson and Johnson (2017) is based on a belief that a successful outcome is a group effort, where "one cannot succeed unless the other members of the group succeed (and vice versa)." This learning strategy has to be planned well ahead and facilitated by an instructor where the teaching and the learning process is designed with a "positive role independence"

structured in. The strategy requires facilitating a situation where students see the advantage of working together, which is not always a straightforward task. In this scenario a specific role, let it be a leader, facilitator, record keeper, or secretary, etc., may be assigned to each group member to attain a "mutually shared group goal." In *promotive interaction* students "promote each other's success" by "assisting, encouragement, and support" in face-to-face activities. *Individual accountability and personal responsibility* is critically important in group based goal oriented settings and require assessment of individual performance with feedback given to group members for improvement. Johnson and Johnson (2017) gave a useful strategy of meeting this requirement "by giving an individual test to each student and randomly selecting one student's work to represent the efforts of the entire group." *Social skills* are important in group interaction as well as communication, leadership, trust-building, and conflict-resolution abilities.

The mentioned elements are essential features of teamwork skills in any group work setting. The topic of teaching teamwork principles in one of the courses in an electrical engineering technology program is the subject of a subsequent section. In group learning, the group needs to reflect on their own activities and draw conclusions on what was successful and what was not. The analysis of group performance may include reflections on the most helpful contributions by individuals, possible ways to improve outcomes by individual contribution within group, etc. Cooperative learning may include, according to Smith, Johnson and Johnson (1992): "informal learning groups" that focus on short time assignments in less structured settings , "formal cooperative learning groups" that are longer in time duration in more formal settings, and "cooperative base groups" designed for long-term "peer support and accountability." Other approaches may include "circles of learning" (Johnson, Johnson, Holubec and Roy, 1984), jigsaw method, student teams formed by Slavin's technique as in "Student Team Achievement Divisions" (STAD) (Slavin, 1990), techniques of "Structural Approach" by Arends (1997), among others. In engineering settings the preferred choice has been a formal cooperative group for projects, laboratory work, and capstone assignments.

Many authors discussed and listed the advantages of collaborative learning including: changing students from passive receivers of information to active participants, improvement in critical thinking, problem-solving skills, communication, social and teamwork skills, and making students more responsible for their own progress in the educational process (Barkley et al., 2014; Bruffee, 1984, 1993; Felder, 2010; Felder and Silverman, 1987; Goodsell et al., 1992; Granger and Lippert, 1999; Griesbaum and Görtz, 2010; Johnson and Johnson, 2013, 2017; Johnson, Johnson, Holubec, 2013; Johnson and Johnson, Smith, 1998, 2014; Kagan, 1994; Mason, 1972; Meyers and Jones, 1993; Nerona, 2017; Rennels, 1993; Slavin 1990; Smith, 1986, 1989; Smith, Johnson and Johnson, 1992; Smith and MacGregor, 1992; among others). Ruiz-Gallardo et al. (2012) reported based on their empirical study a positive impact of cooperative student-centered teaching on improving "teamwork, self-understanding, communication, decision making, and leadership skills" in self-perception assessment although without presence of a control group. Barkley et al. (2014) in their review of collaborative learning literature reported an increased "student persistence" and "motivation" level. Recently, Nerona (2017) reported an empirical study performed in various engineering courses, which showed that collaborative learning "attained significantly better learning outcomes than the lecture groups in areas of collaborative learning, problem-solving, feedback, and interaction with peers, group skills, and communication skills." Miller and Peterson (2002) in their review of cooperative learning listed an improved retention, a positive behavioral climate, and ability to serve better students with disabilities. Barkley et al. (2014) in their book reported a correlation between participation in collaborative learning and improvement in higher-order thinking and learning skills beyond cognitive skills. Similarly, Pascarella and Terenzini (1991) deduced that advantages of collaborative learning go well beyond just cognitive and intellectual skill sets and reach "attitudinal, psycho-social, and moral dimensions."

Heffernan (2015) in her analysis of business management settings mainly outside academia pointed

out the advantages of collaborative activity which offers an increased productivity, creativity, and overall more successful outcomes for organizations. She contrasts traditional competitive business settings leading to "aggression, dysfunction, and waste" within organizations with "creative collaboration" supported by "social capital" based on trust and social connectedness. Heffernan (2015) cautioned, however, about "echo chambers" and importance of having "constructive conflict" within group settings.

Regarding collaborative activities in academic settings researchers noted some concerns or negative experiences caused by a lack of sufficient preparedness and maturity on the part of students, resistance, and uneasiness of changing learning and teaching ways (Göl and Nafalski, 2007). MacGregor (1992) pointed out student's hesitation to get involved with collaborative and cooperative activities due to apprehension, misconception or preconceived notion that cooperation does involve a certain level of obedience or may involve cheating. Barkley et al. (2014) listed concerns such as inequitable participation, student resistance, poor attendance, and other behaviors which adversely affected group work.

Barkley et al. (2014) wrote that the research suggests that nontraditional students prefer and value collaborative and cooperative learning more than traditional students. In the light of the fact mentioned above, that the current college student population is increasingly comprised of older, non-traditional students, it seems that higher learning institutions should support collaborative learning in their academic offerings and provide backing for faculty who engage in those types of activities.

With their handbook, Barkley et al. (2014), provide a very useful resource for teachers on collaborative work and how to implement it in a university setting.

Collaborative or cooperative learning environments differ from competitive and individualistic learning settings with different value systems, pedagogical methods, and the level of students' involvement and participation in the process (Johnson and Johnson, 2013, 2017; Johnson, Johnson, and Smith, 1998; MacGregor, 1992). Overall, cooperative learning has to be well designed and structured by an instructor. The educational objectives must be formulated clearly with specific roles assigned within groups, sometimes on a rotating basis depending on the duration of assignments. Barkley et al. (2014) discussed various collaborative learning techniques (CoLTs) organized into the following categories of general learning activities: "discussion, reciprocal teaching, problem solving, information organizing, writing, and using games." Whatever collaborative activity is chosen a careful planning must be paid to all five stages of the learning process (Barkley et al., 2014):

- Before (preparation – group assignments, time schedule for tasks)
- Beginning (explanation of objectives, setting the expectations)
- During (facilitating, monitoring)
- Ending (presenting the findings)
- After (analysis of results, reflection, strengths and weaknesses, possible improvements).

Barkley et al. (2014) in their book clarify what activities do, and more importantly, what activities do not constitute a collaborative and cooperative learning, which could be helpful for any instructor who attempts to set-up a proper pedagogical environment with any type of collaborative learning.

Kirschner et al. (2004) in their review of literature, drawing examples from science and medical education in "the context of expert-novice differences, cognitive load and cognitive architecture," compared the effectiveness of unguided and guided learning and pointed out that the "evidence from empirical studies over the past half century consistently indicates that minimally-guided approaches are less efficient than learning approaches that place a strong effort on guidance of the student learning process." Thus, a mistake would be to turn group members "loose" and let them function in an unguided setting. Collaborative learning requires preparation and selection of the right pedagogical methodologies with carefully designed student engagement in a guided learning. Consequently, the preparation and implementation of a collaborative or cooperative learning process cause a series of

challenges to educators for various reasons. Gillies et al. (2008) pointed out "that many teachers often do not have a clear understanding about how to establish effective cooperative groups, [of] the research and theoretical perspectives that have informed this approach, and how they can translate this information into practical classroom applications."

Gillies et al. (2008) also noted that lack of time for learning about peer-mediated approaches and introducing them in a classroom vis-à-vis increased responsibilities, needed a strong "commitment to embedding the procedure into the curricula and implementing, monitoring, and evaluating it." Gillies et al. (2008) provide guidelines and useful suggestions on implementation of collaborative learning.

There is no doubt that collaborative and cooperative modes of learning require additional efforts on the part of an instructor compared to traditional educational settings. After all, as Wankat and Oreovicz (1994) pointed out, "students who have been pitted against each other for years cannot be expected to suddenly blossom as cooperators without some practice and guidance." Faculty offering collaborative learning should expect administrative backing (Smith, Johnson and Johnson, 1992), which may include training and other appropriate support measures, to ensure successful learning outcomes.

3. Learning Styles and Teaching Styles: Topic Revisited

In the 1980s and 1990s, academia proposed an experiential learning style theory (Kolb, 1984; Felder and Silverman, 1987; Stice, 1987) which asserted that learning effectiveness depends on matching teaching of teachers and learning styles of students. Regarding engineering education, Felder and Silverman (1987), pointed out that there may be a mismatch in engineering programs between students and professors with regard to the preferred learning styles of students and teaching methods chosen by the instructors. They postulated that learning outcomes could be improved if there is a match between the teaching methodologies chosen by teachers and the learning styles of the students.

It was the author's conjecture (Gapinski, 1994) that relative to engineering programs, engineering technology program instructors tend to be more application oriented and consequently may offer a better match with learning style of the students.

Since 1990s, Felder (2010), Sternberg et al. (2008) among others, focused their research effort to show that matching teaching methods to the learning styles of students would improve learning outcomes. Has been the assertion proven right?

Pashler et al. (2008) published a paper in which the authors claim that there is no strong scientific evidence that supports the "matching idea" of teaching and learning styles. Pashler et al. (2008) do not dispute the existence of learning styles but state that "no one has ever proved that any particular style of instruction simultaneously helps students who have one learning style while also harming students who have a different learning style" (Glenn, 2009). Pashler et al. (2008) pointed out various reasons as to why the "meshing hypothesis" (matching teaching to learning styles) might have attained great influence in the educational field. Among them: the success of the Myers-Briggs categorization in predicting people's occupational decisions or appeal of the notion that instruction not tailored to learning style, and not lack of efforts or aptitude of a learner, is responsible for unsuccessful learning. Pashler et al. (2008) pointed out an existence of an educational business associated with the promotion of learning styles literature, seminars, training and testing material for schools and businesses which helped to publicize the matching concept. They listed, as an example, testing material commissioned by the National Association of Secondary School Principals for testing learning-styles (Keefe, 1988). Interestingly, Pashler et al. (2008) suggested a possible connection between the appearance of "meshing hypothesis" and "the self-esteem movement," which rose to prominence around the same time, in the 1970s.

According to Pashler et al. (2008) very few authors presented empirical evidence to substantiate the claim and none of them pass the scientific requirement of testing on a randomized selection of students.

Gleen (2009) wrote that in the eyes of Pashler et al. (2008) the empirical study presented by Sternberg et al. (1999) that substantiated the matching argument where "students who were strongly oriented toward 'analytical,' 'creative,' or 'practical' intelligence did better if they were taught by instructors who matched their strength," was "'tenuous.'" Pashler et al. (2008) concluded that instructors should not be concerned very much with the learning styles of their students, but rather devote their attention to matching the instruction's methods to the content being taught. While some concepts are best taught via hands-on oriented methods, others are best delivered through lectures or group based assignments or discussion sessions. Pashler et al. (2008) indicated that "at present…the widespread use of learning-style measures in educational settings is unwise and a wasteful use of limited resources." Proponents of the meshing hypothesis defend the findings and point out the extensive literature on the subject.

Fedler (2010) in his critique of the detractors of "meshing hypothesis" points out that a significant body of empirical research indicate a correlation between engineering students' performance and attitudes and their learning styles. Further, he writes that learning styles detractors are missing the point and that "teaching to address all categories of a learning styles model is not a radical idea and specific suggestions for how to do it should look familiar to anyone who has studied the literature of effective pedagogy." So it seems that Fedler (2010) in his critique of detractors and in the defense of the meshing hypothesis states that the key is the right mixture of teaching styles to match the various learning styles.

So, while it appears that the assertion of "meshing hypothesis" is currently inconclusive there is an unforeseen consequence of the educational trend of focusing on learning styles. Namely, Glenn (2009) writes "the mere act of learning about learning styles prompts teachers to pay more attention to the kinds of instructions they are delivering." So, it seems that an increased level of awareness and attention to the learning styles of students prompts instructors to experiment in the delivery methods and to offer, as a result, a richer variety of pedagogical approaches in attaining the teaching objectives. And these efforts through enriching the learning environment may contribute to an improvement of the teaching skills of instructors and consequently of learning outcomes, and facilitate a more nurturing learning environment.

4. Collaborative Activities and Collaborative Learning in Engineering

Long before the concept of collaborative activity appeared in the lexicon of psychological and pedagogical literature, collaborative activities were used for engineering undertakings since antiquity. Various civilizations built marvels of architecture and engineering on vast scales such as cities, pyramids, ports, irrigations systems, canals, aqueducts, bridges, etc., using collaboration in the planning, design, and implementation stages. So working together toward a common goal was and continues to be an essential part of most engineering activities. Engineering education was employing various elements of collaborative activities from the beginning of the establishment of engineering programs in the USA in the 19th century. Although, many if not most of engineering courses are still delivered traditionally through lecture type of activity with students being passive recipients of knowledge (Felder and Silverman, 1988; Goodsell et al., 1992; Nerona, 2017), the situation has been changing. An interest in collaborative learning increased in the last few decades due to the advancement in the understanding of cognitive processes developed by disciplines such as psychology, and the behavioral and social sciences that offered new insights and possible ways to improve the learning process. More recent pedagogical scholarship has offered new "permutations" for group work such as process-oriented guided inquiry learning (POGIL) and peer-led team learning (PLTL) (Barkley et al., 2014). Current pedagogy attempts to build learning communities and teams beyond campus settings and into the online domain (Varma-Nelson, 2018). Engineering education is in the forefront of pedagogical knowledge and methods and is constantly adopting methodologies from other fields of education as well to improve learning outcomes.

Today, the pedagogical repertoire of engineering education related to collaborative learning is quite rich ranging from short-term informal and formal group activities to long-term less or more structured group based assignments. The learning and teaching activities in most cases are campus based, but increasingly involve distributed classroom environments with digital technologies (Clark and Maher, 2006; Gapinski, 2012a&b; Lazakidou and Retalis, 2010; Varma-Nelson, 2018).

Many authors provide guidelines and suggestions on how to set up learning environments with collaborative activities (Burns, 2016; Johnson, Johnson and Holubec, 2013; Johnson and Johnson, 2017; Johnson, Johnson, and Smith, 2014; McCown, 1994; Smith 1989; among others) applicable to engineering. In their review of various collaborative learning techniques mentioned above, Barkley et al. (2014) discuss the following methodologies: think-aloud pair problem solving (solving problem aloud with a peer), send-a-problem (group solves a problem and sends solution to the next, etc.), case study (analysis of real-world scenario), structured problem solving (structured setting), analytic teams (critical analysis, rotating the roles of members), and group investigation in the category of problem-solving collaborative techniques. Felder and Silverman (1988) offer practical teaching approaches used by collaborative learning activities such as, for example: providing intervals in traditional teaching where students working in small groups tackle brainstorming activities or an assignment of drill-like exercises to small groups. Göl and Nafalski (2007) discussed various forms of collaborative learning used at their engineering program, which comprised of: group work in laboratories, short-term team projects, and capstone group projects, which are still the dominant collaborative learning settings in most engineering programs today worldwide. Nerona (2017) reported improvement of effectiveness of learning outcomes in engineering courses such as differential equations, engineering economy, and engineering management when conducted in collaborative settings.

A propensity for collaborative activity in the form of teamwork found its place as one component of expected competencies of engineering graduates expressed by industry (Leake, 1999) and the engineering program accrediting agency - ABET (ABET, 2018).

ABET (ABET, 2018), in its formulated program objectives and student outcomes, expressed specific guidelines regarding expected proficiencies for various engineering programs. ABET program objectives for Electrical Engineering Technology (EET) programs were adopted by the PSU-Fayette campus for its EET program and expressed in terms of the following competencies/abilities:

1. Demonstrate broad knowledge of electrical and electronics engineering technology practices to support design, application, installation, manufacturing, operation, and maintenance as required by their employer,
2. Apply basic mathematical and scientific principles for technical problem solving in areas that may include circuit analysis of both analog and digital electronics, microprocessors, programmable logic control, and electrical machines,
3. Utilize computers and software in a technical environment,
4. Demonstrate competence in written and oral communication,
5. Work effectively as an individual and as a member of a multidisciplinary team,
6. Show awareness of social concerns and professional responsibilities in the workplace, and
7. Matriculate into a baccalaureate degree and/or continue their professional training and adapt to changes in the workplace, through additional formal or informal education.

Many of these expected competencies are attained through collaborative activities in course work either in lecture, laboratory experiments, or projects. Collaborative activities include various forms of informal ad-hoc groups formed for short duration to tackle smaller engineering problems to formal longer in duration capstone final projects (Gapinski, 1994, 1997).

Industry has a permanent voice in ensuring the quality of the PSU-Fayette EET program by advising the campus program through the EET Industrial Advisory Board (IAB) (Gapinski and Sokol, 1994).

In frequently administered surveys, employers of campus graduates continuously stress the

importance of skills related to leadership, communication both oral and written, and collaborative teamwork.

5. Assessment of Learning of Teamwork Principles

Early on in the electrical engineering technology program (EET) courses, to facilitate a teamwork conducive learning environment, the author (Gapinski, 1994) introduces students to the "code of cooperation" adopted from the Boeing Corporation (Evans, D., Linder, D., 1993):

- "Every member is responsible for the team's progress and success,
- Attend all sessions and be on time,
- Listen to and show respect for the contributions of other members; be an active listener,
- Criticize ideas, not persons,
- Resolve conflicts constructively,
- Pay attention-avoid disruptive behavior,
- Avoid disruptive side conversations,
- Only one person speaks at a time,
- Everyone participates – no one dominates,
- Be succinct, avoid long anecdotes and examples,
- No rank in the room,
- Attend to your personal comfort needs at any time but minimize team disruption, and
- Have fun."

The above listed behavioral guidelines, one may note, share many commonalities with canons of good savoir-vivre or business etiquette. In the author's experience, plain discussion and review of these guidelines of expected behavior and conduct sets the proper stage for a productive environment in team based activities.

Through instructions dedicated to teamwork principles and teamwork assignments, students in the EET program develop the skills for collaborative teamwork. The idea is to expose students to the topic from many application oriented contents and reinforce the taught principles. The program, throughout the progression of courses, many with laboratory components, allows for students to build on previous course experiences and consequently to strengthen their teamwork skills.

The teamwork principles were taught as a segment in a course dedicated to ethics for sophomore engineering and science students at Penn State – Fayette campus (Gapinski, 2017). The course was structured to teach canons of ethics, morality, and teamwork skills. The author, motivated by the result of Fitzgerald el al. (2003) who have shown that the accurateness of self-assessment rating was proven to be "reasonably stable when compared with stability of actual performance," used self-assessment by students to assess the learning outcomes. To assess the effectiveness of learning the teamwork attributes the author used the questionnaire by Carr et al. (2005), administered in pre-test and post-test formats. In self-assessment students were asked to evaluate their skills listed in Table 1 using a seven point Likert scale (from 1-srongly disagree to 7-strongly agree; see Appendix A). The results were analyzed and used to test the eleven hypotheses formulated for variables or items listed in the questionnaire posted in Appendix A.

For the purpose of assessment of the effectiveness of learning teamwork principles (Table 1) the hypotheses were formulated for each skill set listed. It was decided to assess the effectiveness of learning and understanding teamwork principles on an individual skill basis using self-assessment by students. To facilitate the assessment, the eleven hypotheses were formulated and tested to reflect eleven essential teamwork skills based on: listening, communication, leadership, adaptability to differences in work styles and cultural norms, coaching ability, ability to provide feedback/evaluate, skill

to negotiate, among others using the list presented by Carr et al. (2005) (see Table 1). Notation wise the "j" subscript denotes jth teamwork skill as listed in Table 1.

Null hypothesis H_{oj}: There is no difference in sample means: $\mu_{0j} - \mu_{aj} = 0$; which represent no improvement in understanding of teamwork skill jth as enumerated in Table 1 for j = 1,…,11.

Alternative Hypothesis H_{aj} : the sample mean of post-test, μ_{aj}, is smaller than mean of pre-test, μ_{0j}: $\mu_{0j} - \mu_{aj} > 0$; which represent improvement in understanding of teamwork jth skill.

Thus, the rejecting of the Null jth Hypothesis and accepting of the Alternative one shows that the learning and comprehension of jth Teamwork skill (see Table 2) was effective. Alternatively, rejecting of the Alternative Hypothesis, H_{aj}, shows that there was no improvement in understanding of specific skill, jth.

Table 1. Teamwork skills (Carr et al., 2005)

Item	**I need to improve:**
1	Listening skills
2	Skills to evaluate the performance of other team members
3	Skills to provide constructive feedback to team members
4	Skills to receive feedback from other team members
5	Coaching skills
6	Negotiating skills
7	Skills to communicate with other team members
8	Skills to manage a team project
9	Skills to be a team leader
10	Skills to adapt to differences in team members' work styles
11	Skills to adapt to different cultural norms of team members

Assuming a significance level $\alpha = 0.05$ or 5% the following hypotheses H_{aj} (j = 1, 4, 5, 7, 10, 11) are rejected: 1. Listening skills, 4. Receiving feedback, 5. Coaching skills, 7. Skills to communicate, 10. Skills to adapt to differences in work styles and cultural norms, 11. Skills to adapt to different cultural norms. The hypotheses H_{aj} (j = 2, 3, 6, 8, 9) are accepted: 2. Skills to evaluate the performance of others, 3. Skills to provide feedback, 6. Negotiating skills, 8. Skills to manage the team, 9. Leadership skills. For details, see Table 2.

Table 2. Results of Hypotheses Testing

Variable/Item	1	2	3	4	5	6	7	8	9	10	11
P-value	.093	.043	.039	.107	.141	.015	.224	.01	.004	.392	.229
Hypothesis Rejected	H_a	H_0	H_0	H_a	H_a	H_0	H_a	H_0	H_0	H_a	H_a
Hypothesis Accepted	H_0	H_a	H_a	H_0	H_0	H_a	H_0	H_a	H_a	H_0	H_0

The sample of statistical data based on hypotheses (Hypothesis 1 and 2) testing using Excel are provided below (Table 3 and Table 4):

Table 3. Variable 1: I need to improve listening skills

	Pre-Test	Post-Test
Mean	3.17	2.6
St. Error	0.35	0.23
Median	2.5	2.0
Mode	2.0	2.0
St. Deviation	1.71	1.05
Sample Variance	2.92	1.09
Kurtosis	-1.45	1.03
Skewness	0.28	1.54
Range	5.0	3.0
Minimum	1.0	2.0
Maximum	6.0	5.0
Sum	76	52
Count	24	20

t-Test: Two-Sample Assuming Unequal Variances

Item	Pre-Test	Post-Test
Mean	3.17	2.6
Variance	2.93	1.09
Observations	24	20
Hypothesized Mean Difference	0	
df	39	
t Stat	1.35	
P (T<=) one-tail	.093	
t critical one-tail	1.68	

Conclusion: Ha1 is rejected.

Table 4. Variable 2: I need to improve skills to evaluate the performance of other team members

	Pre-Test	Post-test
Mean	3.8	3.1
St. Error	0.29	0.29
Median	4.0	3.0
Mode	4.0	2.0
St. Deviation	1.43	1.33
Sample Variance	2.06	1.78
Kurtosis	-1.23	-1.20
Skewness	0.12	0.09
Range	4.0	4.0
Minimum	2.0	1.0
Maximum	6.0	5.0
Sum	92	62
Count	24	20

t-Test: Two-Sample Assuming Unequal Variances

Item	Pre-Test	Post-Test
Mean	3.83	3.1
Variance	2.058	1.779
Observations	24	20
Hypothesized Mean Difference	0	
df	41	
t Stat	1.75	
P (T<=) one-tail	.043	
t critical one-tail	1.68	

Conclusion: Hypothesis H_{a2} is validated.

The tests were performed for one cohort of Science, Technology, and Society (STS 233) Ethics and the Design of Technology course of sophomore science and engineering students. The results showed that the teaching segment of the course dedicated to teamwork principles offered an improvement in understanding of the most important elements of teamwork skills such as: skills to evaluate the performance of others, skills to provide feedback, in negotiation, team management, and leadership. The results will be taken into account in future EET course offerings in order to plan appropriately and focus on areas where improvements can be made. Although the majority of students were at a sophomore level, they had already taken courses in science and engineering courses, which have a component of teamwork based projects, so they were exposed to teamwork principles and that may explain the lower progress than expected in improving of understanding of some teamwork skills.

6. Conclusions

The article reviews collaborative and cooperative learning approaches utilized in higher learning institutions today. As institutions of higher education face multiple challenges such as: student attrition rate, student passivity and isolation, reduction of financial support by states' legislatures, they focus on

improving the efficiency of the educational process. It was hoped that collaborative learning can provide new solutions in improving learning processes. As collaborative learning was being implemented on a wider and wider scale by educational institutions, the growing body of empirical evidence indicates its positive contributions in addressing education's shortcomings. In engineering education, collaborative activities contribute to positive learning outcomes and strengthening of the professional skills required by industry. The article provides an example of an assessment of effectiveness of learning teamwork principles based on a self-assessment by students using pre- and post-test format performed in an engineering ethics course taught by the author.

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Appendix A

Item	I need to improve:	1 SD	2 D	3 SD	4 N	5 SA	6 A	7 SA
1	Listening skills							
2	Skills to evaluate the performance of other team members							
3	Skills to provide constructive feedback to team members							
4	Skills to receive feedback from other team members							
5	Coaching skills							
6	Negotiating skills							
7	Skills to communicate with other team members							
8	Skills to manage a team project							
9	Skills to be a team leader							
10	Skills to adapt to differences in team members' work styles							
11	Skills to adapt to different cultural norms of team members							

Scale: 1-Strongly Disagree 2-Disagree 3-Somewhat Disagree 4-Neutral 5-Somewhat Agree 6-Agree 7-Strongly Agree. Source: Carr et al. (2005)

An Empirical Analysis: Intervention Alternative to Reduce Readmission of Chronic Obstructive Pulmonary Disease (COPD) Patients

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Abstract

The U.S. ranks last among healthcare systems in the world due to inadequate access, operational inefficiencies, and poor health outcomes; but first in expenditures. One reason behind these dynamics is the high preventable readmission rates being experienced by hospitals across the country. In order to improve the quality of care and reduce cost, Medicare and Medicaid impose a penalty to hospitals with excessive preventable readmissions under the Hospital Readmission Reduction Program (HRRP). The HRRP has a direct impact on the hospital's financial performance when treating patients with chronic diseases, such as chronic obstructive pulmonary disease (COPD). COPD is the third common cause of hospital readmissions and morbidity. One of the ways to reduce hospital readmission rate that has been successfully used in other chronic diseases such as heart failure is a follow-up call. The aims of the study are: 1) evaluate the impact of a post-discharge follow-up call on Medicare patients with COPD. 2) compare financially the impact of the penalty imposed by HRRP vs. the simulated intervention. The simulated intervention is applied to 3,448 hospitals that provided inpatient services to Medicare patients with COPD. The proposed intervention assumes a reduced readmission rate of 88% (e.g., 30-day readmission), freeing up 369 hospitals from financial penalties due to HRRP. Moreover, this intervention would have cost less to the healthcare system than the penalty from readmission imposed by HRRP (estimated intervention cost of $28.2 Million versus HRRP penalty cost of $ 5.2 Billion for the fiscal year 2017).

1. Current US Healthcare

In the last decade, US healthcare expenditures have increased dramatically. Over the last five years, these expenditures increased on average 18% of all expenditures in the US, more than twice the rate of other developed countries, which was 8% (World Health Organization 2014). However, these expenditures were not translated into quality improvements. In 2014 the US healthcare system was ranked 50th from 55 countries in inefficiency (Bloomberg 2016). The US healthcare system is continuing to encounter significant challenges in quality healthcare delivery.

2. Hospital Readmission Reduction Program (HRRP)

In the last decade, US healthcare expenditures have increased dramatically. Over the last five years, these expenditures increased on average 18% of all expenditures in the US, more than twice the rate of other developed countries, which was 8% (World Health Organization 2014). However, these expenditures were not translated into quality improvements. In 2014 the US healthcare system was ranked 50th from 55 countries in inefficiency (Bloomberg 2016). The US healthcare system is continuing to encounter significant challenges in quality healthcare delivery. Moreover, to measure a diagnosis for a hospital, the hospital must have at least 25 primary hospitalizations. Excess readmissions are

measured using a hospital performance regarding readmission of those conditions and then compared to the national averages. The hospital's readmission rates are adjusted for age, sex, and co-existing conditions. The penalty is considered as percentages of total Medicare payments to the hospital, and these percentages were set at 1% for 2013, 2% for 2014, and 3% for 2015. The penalties assessed to hospitals are an investment for the CMS.

Among the medical community, the HRRP has gained significant attention, both positive and negative. A previous study showed significantly declined readmission rates for hospitals with AMI, HF, and pneumonia after HRRP was implemented (Desai et al. 2016). Similarly, another study provided significant evidence on reduced readmission rates for AMI's patients (Mellor et al. 2017). In contrast, a study stated that the intention of HRRP is unclear, where the authors could not find any substantial evidence that HRRP contributed in readmission reduction in the New York state (McGarry et al. 2016). Hence, previous studies show conflicting results on hospital readmission rates of patients with a chronic disease included in the HRRP.

3. Chronic Obstructive Pulmonary Disease (COPD)

Chronic Obstructive Pulmonary Disease (COPD) is a long-term lung inflammatory syndrome affecting the respiratory system with typical clinical symptoms of chronic and productive sputum, breathlessness/dyspnea, recurring cough and wheezing (Chen & Mannino, 1999; Wong, 2001). It is one of the world's most common chronic disease and also the common primary diagnosis for hospital admission and readmission (Anderson et al., 1999; Kwok et al., 1999; Mannino, 2002; US National Heart, Lung, and Blood Institute [US NHLBI] & World Health Organization [WHO] 2001; Shipton 1997). Research shows that by the year 2001, up to 600,000,000 people have been stricken by COPD worldwide (US NHLBI & WHO, 2001), and each year about two million deaths are due to chronic lung disease (Gulsvik 2001).

Besides, COPD results in nearly $50 billion in healthcare expenditures annually (Prieto-Centurion et al. 2013). According to the CMS's reports from 1998 to 2008, COPD affects individually as many as 24 million people in the U.S. Also; this number is increasing each year by approximately 18% (Agency for Healthcare Research and Quality [AHRQ], 2011). There are over 800,000 hospital discharges for COPD every year in the United States (Prieto-Centurion et al. 2013). From these discharges, about one in five Medicare beneficiaries are readmitted within 30 days. Consequently, leading COPD to be the third most common reason for hospital readmissions.

3.1 Readmission from COPD and Challenges

Many scholars have argued that preventable readmissions are evidence of poor quality of care (McAlister, 2013; Bisognano et al., 2009), creating a potential adverse effect to patients and unnecessary costs (Berwick et al. 2012). Furthermore, between 2003 and 2004 there were unexpected preventable readmissions recorded totaling $ 17.4 billion (Jencks et al. 2009). In 2013, a Robert Wood Johnson Foundation report estimated $17 billion, out of $26 billion of Medicare expenditures, of avoidable readmission cost. For these reasons, the Affordable Care Act (ACA) generated adjusted payment to eligible hospitals as an incentive for readmission reduction. Therefore, CMS established the hospital readmission reduction program (HRRP) that included economic penalties through the Inpatient Prospective Payment System (IPPS) to any hospital with excessive avoidable readmissions. However, this strategy has raised concerns and undesired financial impact on hospitals.

Interventions to Reduce Hospital Readmissions

Typically, interventions are protocols used during the inpatient period or after discharge to ensure

patients follow through physician's instructions to manage their health condition and avoid preventable hospital readmission. The past two decades shows a reduction for preventable readmission rate through implementing interventions that lead to improving quality of care (Russell et al. 2013 & Cline et al. 1998). A study concluded that implementing the intervention in transition care in elderly patients yielded financial and quality improvement (Naylor et al. 2004). A study comparing the standard of care and the bundle group in which patients received smoking cessation counseling, screening for gastroesophageal reflux disease and depression or anxiety, standardized inhaler education, and a 48-hour post-discharge telephone call. After discharge, resulted in no sufficient difference between the two ways for reducing the readmission rate for COPD (Jennings et al. 2015). In 2016, Benzo and his co-authors conducted a study where motivational interviewing-based health coach was used as an intervention for patients with COPD and results showed that health coaching resulted in decreased readmission rates. Another study showed a reduction in hospital readmission rates for patients with COPD by implementing Pulmonologist follow-up office visits (Gavish et al. 2016). Thus, discharged patients with COPD that have communication or contact with a healthcare practitioner soon after their discharge tend to manage their condition and stay out of the hospital.

Past studies have paired discharge medication with specific guidelines, and results showed that a 25% readmission rate when using the guideline versus 31% without this guideline (Richardson el at. 2016). Furthermore, the readmission rate could be reduced by adopting comprehensive care, individual care plan which included education by respiratory nurse, physiotherapy support pulmonary, and three months telephone follow-up (Ko, et al. 2016). Another study utilized an electronic medical record screening tool to identify patients with COPD combined with a therapist-driven protocol, where patients who their scores are less than seven will receive therapy from the nursing staff. Thus, the study declined the readmission rate from 13.6 to 6.1% (Karenv et al. 2016). Another study used telephone assessments, to address whether patients needed more assistance such as self-management, resulting in approximately 11.25% readmission rate reduction (Harris et al. 2016). On the contrary, Lavesen did not find any significant reduction in readmission rates when follow-up calls where used post-discharge (Lavesen et al. 2016). A comprehensive disease management program, where COPD patients were followed up after 90 days of their discharge, and the follow up included visiting patients at home within the first week of discharge to review medications and inhaler technique, education, and multidisciplinary, and this method has reduced COPD-related hospitalization by 30% (Alshabanat et al. 2017). Moreover, Silver conducted a study to compare respiratory therapist and a disease management program, and both have a quite similar reduction for COPD readmission rates (Silver et al. 2017).

Although past studies proved the effectiveness of several interventions, such as follow up calls, treatment guidelines, comprehensive care and use of electronic medical records, on the reduction of readmission rates. There is limited evidence available on readmission risk factors and reasons for readmission to guide hospitals in initiating programs to reduce COPD readmissions. Based on the effectiveness of healthcare practitioners' follow up post discharged on readmission rates. This study explores the financial impact of this type of intervention as an alternative of HRRP to reduce the preventable readmission for COPD patients. Having a better understanding of the financial dynamics among the cost of interventions and the penalties from HRRP will allow hospitals to control readmission rates while delivering a high-quality healthcare efficiently. Furthermore, from a healthcare systems perspective, this study will estimate the number of hospitals that could avoid the HRRP penalty if they implemented the proposed intervention.

4. Methods

4.1 Data

The data for this study was obtained from public use files (PUF) from repositories available on the CMS website. Correctly, the hospital readmissions reduction programs supplemental data file and the Inpatient Medicare Provider Utilization and Payment Data for IPPS FY2017 were used, where the total number of hospitals considered was 3,449 (CMS 2017). The data has the excess readmission rate and the number of cases for each of acute myocardial infarction (AMI), heart failure (HF) and pneumonia (PN). In 2015, HRRP added other conditions to their calculation that have excessive readmission which is: acute exacerbation of chronic obstructive pulmonary disease (COPD), elective total hip and knee arthroplasty (HK) and Coronary Artery Bypass Graft (CABG), and lastly, the adjusted factor for each provider. This study aims to utilize this data to calculate the penalty for each hospital and the total penalty, then implement, via simulation, the follow-up call intervention to evaluate any decrease in the number of COPD cases.

Inpatient prospective payment system

This system was introduced in section 1886 (d) of the Social Security Act and employed by Medicare to reimburse hospitals for inpatient care services that are provided to covered patients. The potential factor for reimbursement calculation is the diagnosis of the admission (not procedures), represented by the diagnosis-related group (DRG) weight. In 2015, Jim Hoffman efficiently presented the $\mathrm{DRG}_{\mathrm{base}}$ equation:

$$DRG_{Base(i.j)} = CMI_{(i)} \times \left[\left(L \times WI_{(i)} + NL \times COLA, if\ applicable \right) \right] \times NOC_{(i,j)} \quad (1)$$

Where (i) represents the provider or hospital, and (j) represents the conditions that will be included in FY 2017. CMI accounts for case max index, L and NL indicate to the labor and non-labor costs, the next element is (WI) term accounts for the socio-economical differences in each geographic location. However, the COLA term is used to indicate the cost of living adjustment, and the NOC term indicates the number of a case for each condition. Also, $\mathrm{DRG}_{\mathrm{Weight}}$ could be used instead of CMI if it is available.

4.2 Calculations for the excess of readmissions

The next element considered in the HRRP is excess of readmissions for the following conditions: acute myocardial infarction (AMI), heart failure (HF) and pneumonia (PN). In 2015, HRRP added other conditions to their calculation that have excessive readmissions which included: acute exacerbation of chronic obstructive pulmonary disease (COPD), elective total hip and knee arthroplasty (HK) and Coronary Artery Bypass Graft (CABG). The excess is calculated using patient-level administrative data for three years. The application of HRRP for FY2017 uses data from June 30, 2012, to July 1, 2015. Hierarchical logistic regression is implemented to account for the average effect among hospitals, offering a risk adjustment approach. The expected readmissions measure, the denominator, is obtained by regressing the specific patient-level data using the average intercept while the numerator is obtained using the average intercept and the specific "residual" for each hospital (Garcia et al. 2015). The calculation for this element is following Eq.2.

$$ERR_{(i,j)} = \frac{Risk\ adjusted\ predicted\ readmission_{(i,j)}}{Risk\ adjusted\ expected\ readmission_{(i,j)}} \quad (2)$$

4.3 Hospital readmission reduction program (HRRP)

In the IPPS final rule for FY2017, an adjustment factor (AF) is employed to all reimbursements billed to Medicare that presents an excess of readmissions for AMI, HF, PN, HK, COPD, and CABG are included in the calculations of the HRRP. The AF depends on the DRG base payment for each specific disease (AMI, HF, PN, HK, COPD, and CABG in FY2017), the number of cases in the period considered, the payments for all admissions made in the period and the excess of readmissions for AMI, HF, PN, HK, COPD and CABG (see Equation 2). The AF affects the total payment for all admissions billed to Medicare through IPPS during the fiscal year, so if the AF is equal to one, it means a particular hospital will be fully reimbursed, but in the case AF is less than one means the hospital who has this AF will be penalized, and the penalty will reach up to 3%. The following equation shows the elements that AF depends on.

$$AF\left(i\right)=1-\frac{\sum_{j\in J}[(ERR_{(i,j)}-1)\times DRG_{Base(i,j)}\times NC_{(i,j)}]}{DRG_{alladmissions(i)}} \quad (3)$$

Where NC indicates the number of the case for each condition such as (AMI, HF, PN, HK, COPD, and CABG), from the beginning, this methodology attracted criticism. Most of the concerns were related to the inappropriateness of the nature of the incentive (Weixel 2010), the impact on the educational and the vulnerable hospitals (Joynt et al. 2013) or the penalty will be applied for all conditions regardless to which one led to this adjustment (Berenson et al. 2012). Moreover, it is not obvious if the payment deduction will improve the quality of care.

4.4 Simulated Intervention

After reviewing many studies that addressed interventions to reduce the readmission rate for COPD patients in the US, the proposed simulated scenario, an intervention is applied to all COPD admissions under the IPPS of Medicare. The effects on the adjusted factor, as well as the cost, are analyzed to show the differences between implementing this disease-specific intervention with HRRP.

The simulated scenario consists of a single follow-up call from a registered nurse after five days of discharge from the hospital. In this call, the nurse will assess if the patient adhered to the physician discharge orders and check for any other complication that could have followed the transition from the hospital to home. The protocol takes about an hour, including 30 minutes for preparation, planning and recording results, and another 30 min of direct communication with the patient. According to the Bureau of Labor Statistic, the mean annual salary for a registered nurse is $72,180. Therefore, the estimated cost for the following-up call for the simulated intervention will be $34.70 per hour. In order to calculate the impact of the simulated scenario, results from Harris's study (2016) were used where he proved that this intervention led to 11.25% readmission of COPD patients compared to 20% readmission without intervention. The bottom line impact of implementing the follow-up call on the sample data (i.e., 3,448 hospitals, with 815,456 totals number of COPD cases in 2017 FY) was estimated at $28.2 million.

4.5 Procedure

The CMS dataset contained cases of several conditions (including AMI, PN, HF, HK, COPD, and CABG). In order to evaluate the financial impact based on the HRRP for COPD patients, the aggregation formula (Equation 1) was used to calculate the base DRG for each condition, and then calculated the DRG for all admissions. After the simulated intervention was applied, the excess readmission rate for COPD cases was updated by using (Equation 2). The final step entailed updating the AF and identifying which hospitals will be penalized or freed under the simulated intervention.

5. Results

5.1 Base payments

The base DRG for each condition considered by HRRP were computed for each provider, where the average of base DRG for COPD cases before the intervention was $ 1.7 million. The labor and non-labor costs for FY 2017 were $3,839.23 and $1,676.91, respectively. HRRP gave the wage index and case mix for each hospital.

5.2 DRG base payment for all discharge

After calculating the base DRG for each condition using the aggregation formula (Equation 1), the base DRG payment for all admissions was computed. The average base DRG payment for all admissions among the hospitals in the data set was approximately $13.9 million (SD $15 millions), with a range of $5,000 to $126.6 million. Besides, the adjusted payment for FY 2017 is 3%, 2%, and 1%, applied respectively to any hospital with AF equal to 0.97, 0.98, and 0.99 respectively. After obtaining the base DRG payment for all admissions and having the adjusted factor for each provider, the CMS staff adjusts the reimbursement payment to apply the penalty to hospitals with an AF less than 1%. The sum of the individual penalty for each provider resulted in a total penalty for FY 2017 of $ 5.2 Billion.

5.3 The Simulated scenario: post-discharge follow-up call

The simulated scenario, which entailed a single follow-up call from a registered nurse after five days of discharge from the hospital, resulted in a total potential cost of $ 28.2 million. The total cost was determined by calculating the one-hour cost (i.e., $34.7) of a registered nurse per COPD case, where the total number of COPD cases is 815,456.

Then, the penalty cost following HRRP rules was calculated based on the base DRG payment for all conditions by using Equation 1 and the adjusted factor for each provider. The total cost from the penalty resulted in $ 5.2 billion during 2017. Table 1 shows the variation in penalty among the hospitals, and the variation in intervention cost. Since the Patient-Level data is not accessible to the public, the results are not applicable until calculating the new excess readmission rate for COPD.

Table 1. HRRP Penalty for Hospitals versus Potential Intervention cost for COPD cases during 2017

	HRRP Penalty per hospital	Potential Intervention Cost
Range	($17,023-$ 28,663,707)	($ 1,180-$ 94,315)
Mean	$ 1,983,374	$ 10,005
St. deviation (SD)	$ 2,334,624	$ 8,055
Total (*all hospitals*)	$ 5,152,805,800	$ 28,174,977

Figure 1 illustrates the improvement in adjustment factor after implementing the intervention and updating the AF because the number of cases for COPD has been reduced from 815,45 to 93,285 patients, which led to the update of the excess readmission rate for the COPD condition. Some of the hospitals were initially under the penalty because their AF was less than 1%; however, the proposed intervention freed some of them from the penalty. For instance, the hospital in observation 24 had an AF of 0.9997 resulting in a penalty. However, after applying the simulated intervention, its AF would have increased to 1.0, which means no penalty would have been applied. In general, after applying the simulated intervention to the data set from 2017, the total number of hospitals who would have avoided the penalty would have been 670- about 26% out of 2,598 penalized hospitals. Also, improvements on the actual percentage penalty could also be realized with the simulated intervention. For example, 181

hospitals improved their AF to 0.99, which reduces the penalty to 1% instead of 2%, and 49 hospitals improved their AF to 0.98, which reduces the penalty from 3% to 2%. There were three hospitals whose AF jumped from 0.97 to 0.99, reducing the penalty from 3% to 1%.

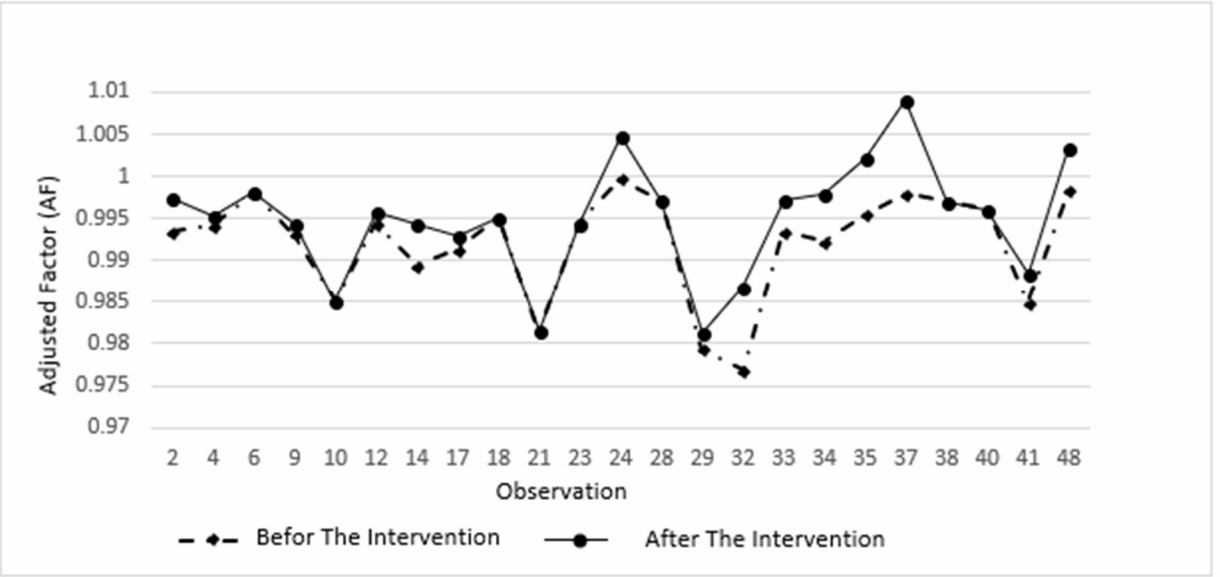

Figure 1. Comparison between FY2017 Adjustment Factor- Before and After Intervention

6. Conclusions

The study included 3,637 US hospitals from the CMS database, all of which covered Medicare patients. After removing hospitals with missing data (i.e., 189), 2,598 hospitals were penalized under the HRRP in 2017. The penalty cost for those hospitals was estimated at $ 5.2 Billion. This study aimed to evaluate the financial impact based on the HRRP for COPD patients. In particular, evaluating the financial impact due to readmissions on the healthcare system by comparing two scenarios: 1) implementing a post-discharge follow-up call (e.g., intervention), vs. 2) penalty imposed by HRRP. In general, results highlighted the importance of interventions to improve health outcomes and potentially reduce the preventable readmission rates for COPD patients. The projected cost to implement the simulated intervention was $ 28.2 Million, compared to $ 5.2 Billion of the total penalty cost of HRRP, during the study period. The results showed a 20% total cost reduction if an intervention is used compared to the penalty cost.

These results could be extended to other health issues that are known to drive hospital readmission rates. For example, acute myocardial infarction (AMI), heart failure (HF), pneumonia (PN), an acute exacerbation of chronic obstructive pulmonary disease (COPD), elective total hip and knee arthroplasty (HK) and Coronary Artery Bypass Graft (CABG). One limitation of this study was the lack of patient-level data, which could have provided more detail and insight on the cause of the readmission and conditions of the patient. For instance, if a patient is in advance stages of COPD, this patient could have been excluded from the study given that readmission would have been unavoidable. Furthermore, for future studies, various types of interventions (such as case management or house visits) could be evaluated to assess their impact on hospital readmission rates.

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Factors Correlating with Revisions of the ISO 9001 Quality Management Standard

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Abstract

Today, the ISO 9001 standard is adopted by more than one million organizations in 170 countries around the world. The standard, which has attracted significant attention of academics and practitioners, applies to quality assurance in design, development, production, installation, and service. The standard sets out quality management system criteria and provides guidelines and tools for organizations and companies to ensure that their products and services meet consumer expectations. Effective implementation of such standard can lead to a significant increase in the company`s performance, stability, and competitiveness. Since its initial publication in 1987, ISO 9001 has been revised four times, often justified by changes in the marketplace. Macroeconomic data representing six categories, used to track market changes from 1987 through 2015, were obtained from various databases. Levels of correlation among factors were quantified using multivariable analysis. By utilizing multiple regression analyses, both U.S. and global sets of data indicated statistically significant trends in the gross domestic product (GDP) over the study period. Consequently, an autoregressive integrated moving average (ARIMA) model was fitted to the U.S. data, which was then used to forecast future revisions of the standard. Results indicated that with a sustained increase in the U.S. GDP, revision periods are expected to decrease. According to the fitted forecasting model, it is expected that revisions of the ISO 9001 standard are likely to take place by 2019. U.S. companies that are certified under ISO 9001-2015 have two years to plan and budget for recertification.

1. Introduction

Quality remains a fundamental criterion of competition, regardless of the concepts currently in fashion (Hill, 1995). Recent product recalls worldwide are further reminders of the central role that quality plays in maintaining competitiveness. Quality improvement measures not only improve product quality but can also enhance productivity, efficiency, and delivery (Bailey, 1998; Olderding, 1998; Zurier, 1989). Quality management has been defined by Bou-Llusar, et al. (2009) as "an approach to management characterized by some guiding principles or core concepts that embody the way the organization is expected to operate, which, when effectively linked together, will lead to high performance." Quality management will remain a significant issue for the foreseeable future. For companies that have implemented the ISO 9001 standard, the basic principles and methods associated with quality management remain useful in building a quality-oriented organization (Chan & Sun, 2004). The standard has been revised four times since its first publication in 1987. Changes in the marketplace have been cited as a justification and driver for these revisions. This research was aimed at identifying microeconomic factors that correlate with the revisions made. The following section presents a review of the literature pertaining to the ISO 9001 standard and models used to track changes in the marketplace. Section 3 presents the data used and the steps followed in identifying possible predictors of the revisions. A detailed discussion of the results and final conclusions are presented in Section 4.

2. Literature Review

Standards are crucial in modern life. They have been fundamental in both the development of complex technologies and the worldwide economy. A standard as defined by the International Organization for Standardization (www.iso.org) is "a document that provides requirements, specifications, guidelines, or characteristics that can be used consistently to ensure that materials, products, processes, and services are fit for their purpose." The ISO 9001 standard sets out the quality management system criteria. It provides guidelines and tools for organizations and companies that want to ensure that their products and services meet consumer expectations. It also seeks to ensure that companies improve the quality of their products and services consistently.

2.1 ISO 9000 Quality Management Standards

The ISO 9000 QMS applies to quality assurance in design, development, production, installation, and service. It was first published in 1987 by the International Organization for Standardization (IOS), an international agency composed of the national standard bodies of more than 170 countries. According to Davis (2013), the ISO 9001 standard sets out management criteria and provides tools and guidelines for which organizations can ensure that their products, services, and processes meet customer expectations. Many models have contributed to the management of quality, but different standards have caused confusion because of the variable quality factors (Bari & Djouab, 2014). In response, the IOS began encouraging and promoting international standards such as the ISO 9000 standards for quality assurance (Manders, deVries, & Blind, 2016). The ISO 9000 family of standards include ISO 9001, ISO 9004, and ISO 19011. The ISO 9000 standard describes the basic concepts and language used to help organizations adopt the ISO 9001 standard. The IOS also has a scope of standards for quality management systems that are based on ISO 9001 and are adjusted to particular sectors and industries. These include the ISO/TS 29001 for petroleum, petrochemical, and natural gas industries; ISO 13485 for medical devices; ISO/IEC 90003 for software engineering; ISO 17582 for electoral organizations at all levels of government; and ISO 18091 for local government. Also, both the Aerospace Quality Management System Family of Standards (AS 9100) and Automotive Quality Management System Standard (IATF 16949) are based on the ISO 9000 standard with additional requirements.

According to Yin and Schmeidler (2009), standardized management systems may be implemented in very different ways, depending on the organization. This may explain the heterogeneous performance of these standardized systems. Their studies have shown that the impacts of ISO 9001 certification have largely neglected this phenomenon. According to the ISO website (www.iso.org), every five years, all ISO standards are reviewed by members to determine whether a revision is required in order to keep it current and relevant in the marketplace. The nature of these revisions has changed over the years to reflect transitions in the way business is done, particularly in the awakening of globalization. When the organization is ready to revise the standard, the members initiate a process that takes two to four months. Experts nominate ISO members to meet and discuss the issues raised (Bredenberg, 2015). The ISO 9001 standard has been revised several times. It was first revised in 1994 relative to its prescriptive and focus on manufacturing. But this was difficult for service providers to interpret and apply. Then it was significantly revised in 2000 to focus on continuous improvement, customer satisfaction, leadership, and process management, with an attempt to make it more applicable to service providers and more flexible. ISO 9001 experienced a minor revision in 2008 involving only slight word changes; no actual requirements were added, removed, or modified. The latest revision to this standard occurred in 2015 and involved a significant revision and another step away from its manufacturing origins. It offers a model for managing and improving an organization. The revision places management at the heart of the standard and offers a framework for long-term success and customer satisfaction.

2.2 Changes in the Marketplace

Today's companies find themselves operating in an environment that is changing more quickly than ever before. Kevin McKinley (ISO 2014), the acting Secretary General of the international Organization highlighted significant areas that motivated revisions to the ISO 9001. He pointed out that the world has changed and that this revision was needed to reflect the change. ISO 9001 allows organizations to adapt to a changing world by improving their capacity to meet customer needs and to provide a consistent foundation for maintaining success. McKinley also stated that globalization, including a reduction in trade barriers and tariffs, has increased. Service-based economies have changed, demanding support from manufacturing companies. Businesses are swapping across borders more efficiently, and standards must reflect these types of changes. In addition, technology is driving increased expectations for customers and businesses. Therefore, organizations need to operate in new ways, and quality management standards must keep up with these expectations. Organizations need to identify external factors within their environment that could influence their plans. A popular tool for identifying these external factors is the political, economic, social, technological, legal, and environmental (PESTLE) analysis. There are many definitions for the PESTLE analysis. Allen (2001) pointed out that, "PESTLE analysis is a tool that can identify factors that can affect the organization and then find a way to overcome these factors." He suggested that PESTLE analysis has two primary functions for a company: it provides the classification of the environment within which the organization operates, and it provides data and information that will allow the company to divine situations and circumstances that it might encounter in the future. Also, Ho (2014) stated that PESTLE analysis involves "tools that have been used for scanning the present and the future external environment when engaging in strategic planning or change management." The PESTLE analysis has been used in different fields (Kolios & Read, 2013; Yüksel, 2012; Shilei & Yong, 2009).

3. Factors Correlating to Revisions of ISO 9001 Standard

In investigating trends in the microeconomic factors, the research started by compiling data on the 35 factors listed under the six key categories of the PESTLE model. The study period was established to include data from 1987 to 2015, i.e., from the year of the first publication of the ISO 9001 standard in 1987 to the most recent version published in 2015. During this period, the standard was revised four times. U.S. market data were compiled from various resources such as the U.S. Bureau of Labor Statistics, U.S. Bureau of Economic Analysis, and U.S. Bureau of Statistics. Global economic data were compiled from the World Bank database.

3.1 Initial Factors of U.S. Data

Investigations into the availability of data pertaining to the 35 economic factors within the study period resulted in identifying only 15 factors. Table 1 shows the list of the 15 factors identified for this study. To quantify the levels of correlation among these 15 factors, a multiple variable analysis as defined by Friendly (2002) was performed using the Statgraphics Centurion software. The results are shown in Figure 1. The correlation matrix indicates values of the Pearson product-moment correlations between each pair of factors. These correlation coefficients range between –1 and +1 and measure the strength of the linear relationship between factors. As can be seen, the gross domestic product (GDP) appears to be linearly correlated with all factors except energy use (0.05) and inflation rate (–0.38). These three factors were assumed to be independent and hence selected for regression analysis.

Table 1. PESTLE factors and fifteen U.S components

PESTLE Factor	U.S. Available Components
Political (P)	• Tax policy • Government spending
Economic (E)	• Gross domestic product (GDP) • Inflation rate • National income market • Capitalization of listed domestic companies
Social (S)	• Population total • Labor force total
Technological (T)	• Research and development • Patent applications • Trademark applications
Legal (L)	• Imports of goods and services • Exports of goods and services
Environmental (E)	• Energy use (kg of oil equivalent per capita) • Crude oil import prices

	GDP	R&D	Taxes	Population	Imports	Exports	Energy Use	Crude oil	Labor	Net Income	Inflation	Capitalization	Spending	Patents	Trademarks
GDP		0.98	0.90	0.99	0.99	0.97	0.05	0.79	0.99	1.00	-0.38	0.92	0.99	0.99	0.85
R&D	0.98		0.86	0.97	0.98	0.96	0.05	0.80	0.98	0.99	-0.32	0.90	0.98	0.99	0.83
Taxes	0.90	0.86		0.94	0.83	0.82	0.30	0.49	0.92	0.90	-0.61	0.91	0.84	0.88	0.91
Population	0.99	0.97	0.94		0.96	0.95	0.10	0.72	1.00	0.99	-0.48	0.92	0.97	0.98	0.90
Imports	0.99	0.98	0.83	0.96		0.98	-0.04	0.88	0.96	0.98	-0.25	0.87	0.99	0.98	0.80
Exports	0.97	0.96	0.82	0.95	0.98		-0.06	0.87	0.96	0.97	-0.30	0.85	0.97	0.95	0.86
Energy Use	0.05	0.05	0.30	0.10	-0.04	-0.06		-0.39	0.09	0.06	-0.30	0.32	-0.07	0.04	0.19
Crude oil	0.79	0.80	0.49	0.72	0.88	0.87	-0.39		0.74	0.79	0.12	0.56	0.86	0.79	0.53
Labor	0.99	0.98	0.92	1.00	0.96	0.96	0.09	0.74		0.99	-0.43	0.92	0.97	0.99	0.89
Net Income	1.00	0.99	0.90	0.99	0.98	0.97	0.06	0.79	0.99		-0.38	0.92	0.99	0.99	0.85
Inflation	-0.38	-0.32	-0.61	-0.48	-0.25	-0.30	-0.30	0.12	-0.43	-0.38		-0.48	-0.29	-0.35	-0.54
Capitalization	0.92	0.90	0.91	0.92	0.87	0.85	0.32	0.56	0.92	0.92	-0.48		0.86	0.90	0.87
Spending	0.99	0.98	0.84	0.97	0.99	0.97	-0.07	0.86	0.97	0.99	-0.29	0.86		0.98	0.80
Patents	0.99	0.99	0.88	0.98	0.98	0.95	0.04	0.79	0.99	0.99	-0.35	0.90	0.98		0.82
Trademarks	0.85	0.83	0.91	0.90	0.80	0.86	0.19	0.53	0.89	0.85	-0.54	0.87	0.80	0.82	

Figure 1. U.S. data and Person product-moment correlations.

In conducting the multiple regression analysis, years were selected as the dependent variable, and the U.S GDP ($U.S. billion), energy use ($U.S. billion), and inflation rate (annual %) were used as independent variables. Forward stepwise regression procedures were utilized as the selection criteria. According to Efroymson (1960), this procedure starts with a model that includes only a constant and brings in factors one at a time, provided that they have significant contributions. The results shown in Table 2 indicate that the GDP is the only significant factor to be included in the model. Similar results were obtained by using the backward elimination procedures [see Montgomery & Runger (2011)] Contributions of both the inflation rate and energy use were not statistically significant at the 5% level and hence were excluded. Table 3 shows the results of the analysis of variance (ANOVA) regarding the statistical significance of the fitted model. Given a p-value < 0.001, the fitted model appeared highly significant. The R^2 statistic indicated that the fitted model explains about 98.5 % of the variability in GDP.

In order to detect violations of the underlying assumptions of the ANOVA procedure, diagnostic examination of the residuals was performed. Residuals represent differences between the actual and estimated values of the dependent variable. Figure 2 shows the normal probability plot of the residuals of U.S. data, which supports the assumption that the residuals are normally distributed.

Table 2. Results of regression analysis (U.S data)

Parameter	Estimate	Standard Error	T-Statistic	P-Value
CONSTANT	1977.15	0.548371	3605.51	0.0000
U.S Gross Domestic Product ($U.S. billion)	0.00214895	0.0000558604	38.4699	0.0000

Table 3. Analysis of variance (U.S. data)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1280.11	1	1280.11	1479.93	0.0000
Residual	19.8944	23	0.864975		
Total (Corr.)	1300.0	24			

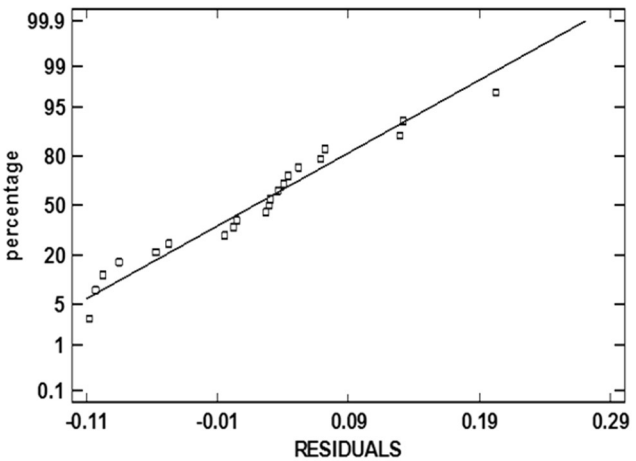

Figure 2. Normal probability plot of residuals of U.S. data.

3.2 Initial Factors of Global Data

Complete records on only ten factors were identified from the World Bank database within the study period. Table 4 presents information about these ten initial factors, which were selected for multiple variable analysis. The results, shown in Figure 3, indicate that the world GDP is linearly correlated with all the factors, except for the world inflation rate. Consequently, multiple regression analysis using forward stepwise regression was performed. Results of the regression analysis and associated ANOVA are shown in Tables 5 and 6, respectively. The reported p-value of < 0.001 indicated a statistically significant linear relationship between the world GDP and the years of the study period. The world inflation rate was ignored due to its insignificant contribution to the model. The R2 statistic indicated that the fitted model explains 90.4% of the variability.

Table 4. PESTLE factors and ten global components

PESTLE Factors	Available Components
Political (P)	• Government spending
Economic (E)	• Gross domestic product • Inflation rate • Adjusted national income market
Social (S)	• Population total
Technological (T)	• Patent applications • Trademark applications
Legal (L)	• Imports of goods and services • Exports of goods and services
Environmental (E)	• Energy use (kg of oil equivalent per capita)

	GDP	Population	Exports	Imports	Energy Use	Net Income	Inflation	Patents	Trademarks	Exenditure
GDP		0.94	0.99	0.99	0.91	1.00	-0.34	0.97	0.96	1.00
Population	0.94		0.90	0.90	0.87	0.94	-0.58	0.98	0.98	0.93
Exports	0.99	0.90		1.00	0.89	0.99	-0.31	0.95	0.94	0.99
Imports	0.99	0.90	1.00		0.89	0.99	-0.31	0.95	0.94	0.99
Energy Use	0.91	0.87	0.89	0.89		0.91	-0.26	0.88	0.88	0.92
Net Income	1.00	0.94	0.99	0.99	0.91		-0.35	0.97	0.96	1.00
Inflation	-0.34	-0.58	-0.31	-0.31	-0.26	-0.35		-0.53	-0.53	-0.32
Patents	0.97	0.98	0.95	0.95	0.88	0.97	-0.53		0.99	0.96
Trademarks	0.96	0.98	0.94	0.94	0.88	0.96	-0.53	0.99		0.95
Exenditure	1.00	0.93	0.99	0.99	0.92	1.00	-0.32	0.96	0.95	

Figure 3. Global data and Pearson product-moment correlations.

Table 5. Results of regression analysis (Global data)

Parameter	Estimate	Standard Error	T-Statistic	P-Value
CONSTANT	1979.93	1.23725	1600.27	0.0000
World Gross Domestic Product ($U.S. billion)	0.00051537	0.0000357614	14.4113	0.0000

Table 6. Analysis of variance (Global data)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1039.85	1	1039.85	207.69	0.0000
Residual	110.15	22	5.00683		
Total (Corr.)	1150.0	23			

The normal probability plot of the residuals shown in Figure 4 supported the assumption that the residuals are normally distributed.

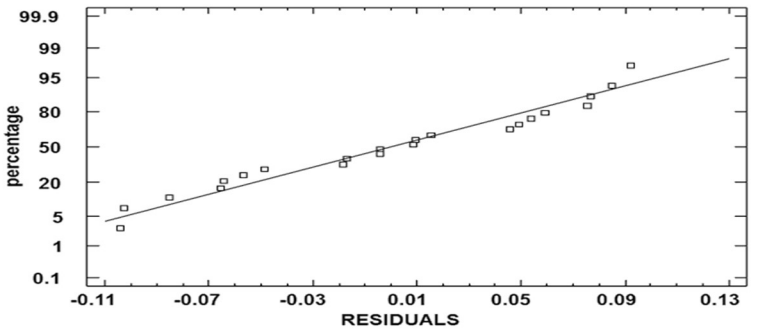

Figure 4. Normal probability plot of residuals of global data.

3.3 Forecasting Models

Regression analyses of both the U.S and global data indicated that the gross domestic product correlates well with market changes over the study period. This section shows how U.S. data was used to select the forecasting model, given its availability and accuracy, as compared to World Bank data. This data includes U.S. GDPt records with t ranges from 1987 to 2008. Data from 2009 to 2017 were utilized for validation of the fitted model. Box et al. (2016) suggested that four steps be followed in the time series analysis: identification, estimation of the parameters, diagnostic checking, and forecasting. The identification stage involves choosing the tentative (p, q, d), where "p" is the order of the autoregressive part, "d" indicates the order of the differencing, and "q" indicates the order of the moving average process. Figure 5 shows that the GDP presents a clear non-stationary time series, reflecting a continuous upward trend over time.

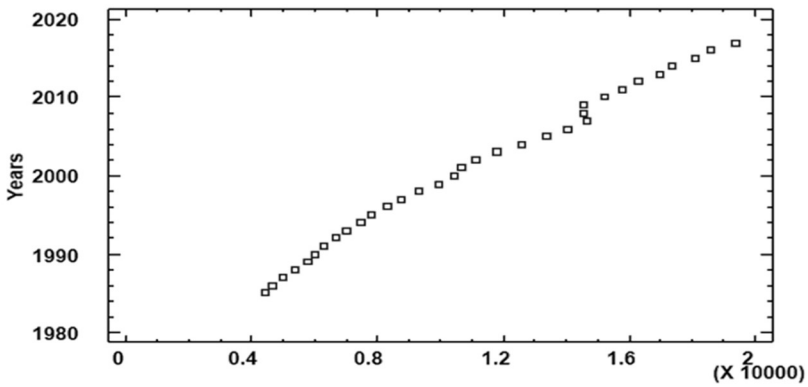

Figure 5. U.S GDP vs years.

An examination of the plot of the autocorrelation function (ACF) indicates a non-stationary time series that needs to be differenced at least once in order to be made stationary. As shown in Figure 6, the ACF decays slowly after lag 1.

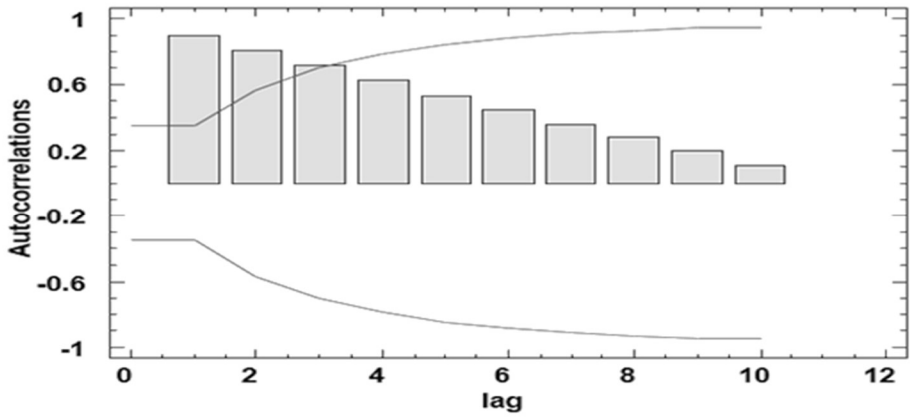

Figure 6. The residual behavior of ACF.

In addition, the strongly trended series has a single spike at lag 1 in its partial autocorrelation function (PACF). This is shown in Figure 7. These results suggested using an autoregressive integrated moving average (ARIMA) model in representing the trend in GDP over the years. Using the model selection function in the Statgraphics, two ARIMA models were compared: ARIMA (1, 1, 1) and ARIMA (1, 1, 0). Table 7 provides a summary of the results and indicates that the ARIMA (1,1,0) model resulted in the smallest values of the root mean squared error (RMSE) and mean absolute percentage error (MAPE). Hence, the ARIMA (1,1,0) model was selected to forecast future trends in the GDP.

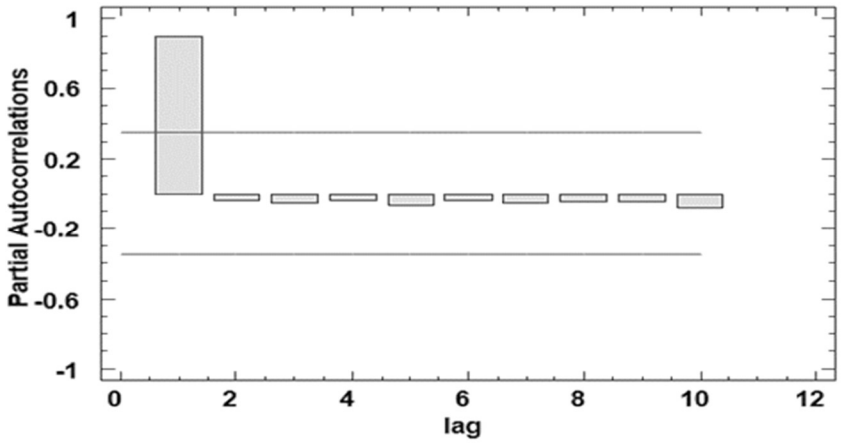

Figure 7. The residual behavior of PACF.

The ARIMA model summary presented in Table 8 shows a p-value < 0.001 for the autoregressive (AR) term. The fitted first-order autoregressive model is given by:

$$GDP_t = GDP_{t-1} + 0.912305\ [GDP_{t-1} - GDP_{t-2}]$$

Table 7. Comparison of Proposed Models

Model	RMSE	MAE	MAPE	ME	MPE
ARIMA (1,1,1)	216.607	139.473	1.39459	21.04	0.357632
ARIMA (1,1,0)	211.675	137.5	1.36097	18.2577	0.327147

Table 8. ARIMA Model Summary

Parameter	Estimate	Standard Error	T-Statistic	P-Value
AR (1)	0.912305	0.0859344	10.6163	0.000000

Table 9 shows forecasted values for the U.S gross domestic product. During the period where actual data is available, it also displays the predicted values from the fitted model and the residuals. The U.S GDP data ($U.S. billion) from the years 2009 to 2017 was used to validate the fitted forecasting model. Figure 8 shows the forecast plot of the ARIMA (1,1,0) model for the U.S. GDP, indicating a linear upward trend projected into the future, with confidence intervals widening much more rapidly.

Residuals from the validation period were used to check the adequacy of the fitted model. The normal probability plot of the residuals approximates a straight-line, indicating that the model residuals are normally distributed as shown in Figure 9.

Table 9. Forecast of U.S GDP

Period (*t*)	GDP_t	Forecast	Residual	Validation
2009	14570.0	14422.3	147.723	V
2010	15230.0	14588.2	641.754	V
2011	15790.0	15832.1	-42.1214	V
2012	16300.0	16300.9	-0.890925	V
2013	17000.0	16765.3	234.724	V
2014	17393.0	17638.6	-245.614	V
2015	18121.0	17751.5	369.464	V
2016	18624.0	18785.2	-161.158	V
2017	19386.0	19082.9	303.11	V

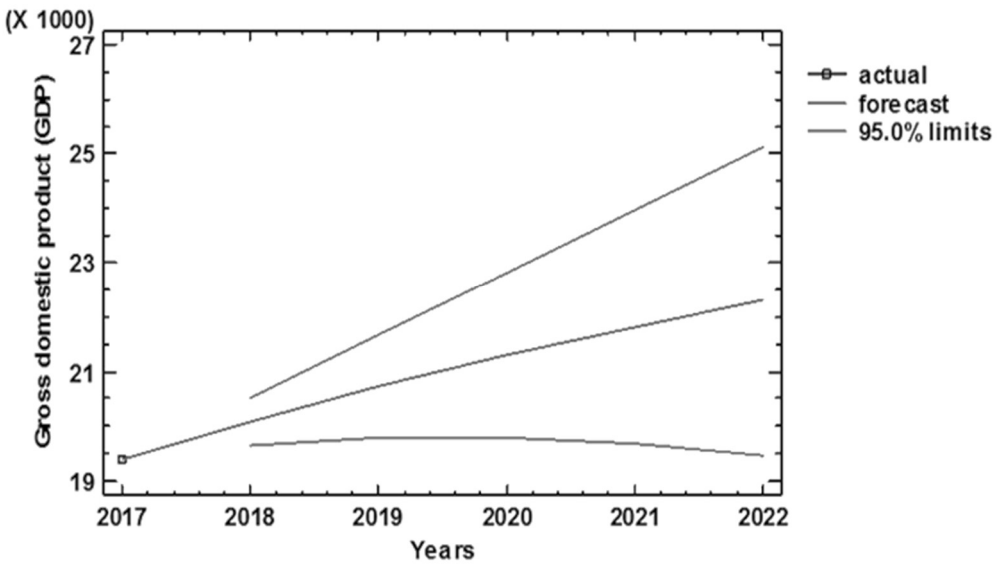

Figure 8. Forecast plot of ARIMA (1, 1, 0) model for U.S. GDP.

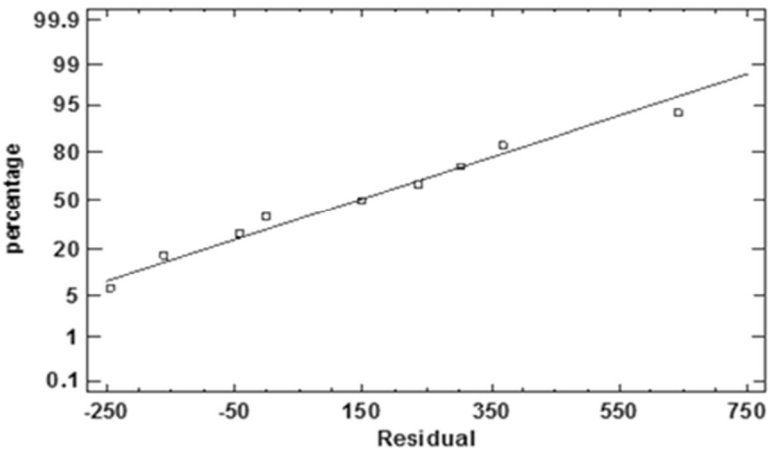

Figure 9. Normal probability plot for validation period

3.4 Forecasting Future Revisions

The ISO 9001 standard has been revised four times since its initial publication in 1987. These revisions did not occur over fixed time intervals. Changes in the GDP preceding each revision are shown in Table 10. A 95% confidence interval for estimating the average difference resulted in differences within \$3,275.25 $\pm$ \$1,118.05. This is an indication that revisions have taken place based on an average increase of \$3,275.25 billion in the GDP.

Table 10. Change in Average U.S GDP

Revision Period	Average GDP (\$U.S. Billion)
ISO 9001: 1994	2,460
ISO 9001: 2000	2,990
ISO 9001: 2008	4,080
ISO 9001: 2015	3,571

As such, the next revision of the ISO 9001 standard would be expected when the reported GDP from the last revision in 2015 increases by \$3,275.25 billion, i.e., at a GDP of \$21,399.25 billion**.** Based on the fitted model, forecasted levels of the GDP over the next five years were obtained. Forecasted values of the GDP together with corresponding 95% confidence limits are presented in Table 11. As shown, the GDP is expected to reach \$21,399.25 level by the year 2019.

Table 11. Forecast Of U.S GDP (\$ Billion) Vs Years

Period	Forecast	Lower 95.0% Limit	Upper 95.0% Limit
2018	\$20,081.2	\$19,647.4	\$20,515.0
2019	\$20,715.4	\$19,779.3	\$21,651.5
2020	\$21,294.0	\$19,779.5	\$22,808.5
2021	\$21,821.8	\$19,676.2	\$23,967.5
2022	\$22,303.4	\$19,489.5	\$25,117.3

4. Discussion and Conclusions

This research was aimed at identifying macroeconomic factors that may correlate to revisions in the ISO 9001 quality management standard. Since its first publication in 1987, the number of certified organizations has grown to include 1.2 million in 2016. Organizations are typically required to recertify to the new version within a transition period of three years. Recertification activities involve both internal and external costs. External consulting costs vary by industry, the number of employees, and the number of sites. The standard has been revised four times, with the last revision published in 2015. Market changes have been cited by the International Organization for Standardization to justify the need for revisions. A review of the literature has indicated that the PESTLE model may be used to identify market changes over time. This model encompasses 35 macroeconomic factors in representing its six elements. Historical data covering the study period from 1987 to 2015 were compiled from published databases for both the U.S. and global markets. Statistical analysis of these data sets pointed to the annual gross domestic product (GDP) as a significant correlate to market changes over the study period. Upward trends in the GDP were modeled using an ARIMA (1,1,0) model and verified based on the GDP data from 2009 through 2017. The fitted model was used to predict future annual values of GDP in the U.S. market. Based on an analysis of historical changes in the GDP, and should the same trend continue in the future, a new revision of the ISO standard is expected to take place as soon as 2019. These research findings have led to the following conclusions:

1. Trends in the GDP for both the U.S. and global markets appear to correlate well with the revisions of the ISO 9001 quality management standard.
2. Given the current trends in the GDP in the U.S., the revision periods of the ISO 9001 are expected to decrease in order to maintain its relevance and effectiveness. If trends in the GDP continue, a new revision of the standard would be expected every five 5 years. Organizations that are certified under ISO 9001-2015 have only one year to plan and budget for recertification.
3. The current revision process employed by the ISO Technical Committee should be re-examined. Given the current trends, a process with a lead time of 40 months will not be appropriate for the projected revision periods. The Technical Committee should seek better methods for collecting user feedback by utilizing electronic media and social networks.

Future research efforts will target calibration of the model as new data become available. Following the methodology employed in this paper, efforts will be made to re-examine macroeconomic data and determine other emerging correlates. This may call for using advanced forecasting methods allowing for the integration of more than one time series.

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The 25th Anniversary of the AIAG FMEA Reference Manual: A Systematic Literature Review of Alternative FMEA Methods.

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Abstract

The Automotive Industry Action Group (AIAG) publication titled *Failure Mode and Effects Analysis Reference Manual* (2008) is currently in the fourth edition and will soon be celebrating its 25-year anniversary. The importance of this document cannot be disputed or understated: It has become the accepted standard for Failure Mode and Effects Analysis (FMEA) guidance, development, and FMEA management both within and outside of the automotive community. Many industries and disciplines such as aerospace AS 13004 (2017) and international electro-technology IEC 60812 (2006) use similar methods to assess and mitigate risk, identify improvement opportunities and document process history. Books such as *Guidelines for and Mode Effects and Analysis For Automotive, Aerospace and General Manufacturing Industries* (2003) describes a similar methodology as presented by AIAG. The FMEA has also become the source of customer mandatory requirements, a critical element/tool of an effective Quality Management System and often a focal point of ISO or other registration scheme audits.

This study used a systematic literature review to identify, review, summarize, contrast and compare alternate FMEA methods as published by other researchers since 1993. The literature review is important to the field of Quality Science as well as Engineering Technology because in the past, many criticisms of the AIAG methodology have been offered, and many have suggested alternative methods, yet these methods have not been compiled into a single research endeavor with a distinct focus on those alternate FMEA methods that offer new methods in the *FMEA development process* vs. risk priority number (RPN) calculation. This research accomplishes this task while answering research questions about FMEA methodology best practices, FMEA shortcomings and concludes with recommendations for further research into FMEA methodology.

1. The Need for a FMEA Related Literature Review & FMEA Overview

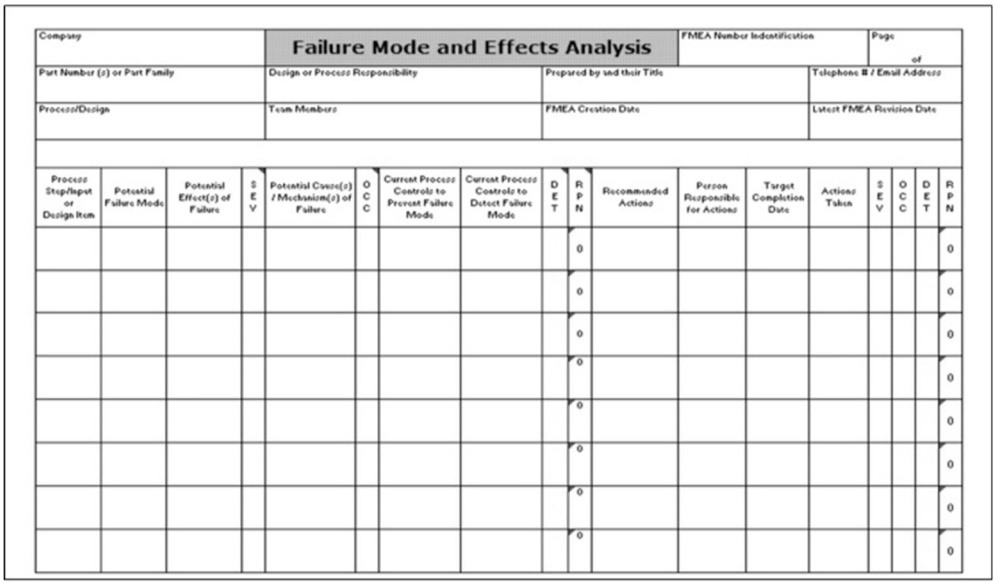
1.1 Necessity for a FMEA Literature Review

Failure mode effects and analysis has been around since 1949 when the military outlined the process and requirements in Mil-P-1629 (1998). Although this standard has since been cancelled in 1998, the methodology for risk assessment has been adopted by various industries such as automotive, aerospace, and healthcare. Some of the most popular and widely used guidance documents include Society of Automotive Engineers, SAE J-1739 (2009), textbooks such as *Guidelines for Failure Mode and Effects Analysis (FMEA) for Automotive, Aerospace, and General Manufacturing Industries (2003),* The Basics of FMEA, and **most notably**, the Automotive Industry Action Group (AIAG) (2008) publication titled *Failure Modes and Effects Analysis Reference Manual* (2008) that is currently in the fourth edition of the document. The initial release was in 1993 and represented a collaborative effort between Ford, Chrysler and General Motors to standardize the FMEA process for automotive component suppliers to assess product and process risk in a effort to improve vehicle quality and safety for the consumer. Since 1993, this publication has been revised on three occasions; the use of this methodology has become a

requirement for most automotive suppliers and is one of the 5 core tools of automotive quality assurance. Most of the automobile manufacturers require the use of this document and process by sub tier suppliers during design and manufacture of automotive components. With the development of quality standards such as ISO 9000:2015, QS 9000 (obsolete in 1998), and TS 16949:2009 (revised in 2016), the FMEA has become not only a required risk assessment tool, but has also become a significant focus and constituent of quality management systems. As a result, the FMEA has become an important, significant document often reviewed during third party audits, customer audits and internal organizational reviews. With the latter noted, the AIAG (2008) FMEA reference Manual and FMEA development process outlined in the manual has received criticism regarding several aspects of the FMEA process and guidelines including the method to calculate RPN and the tables for severity, occurrence, and detection. Researchers Liu, H., Liu, L., & Liu, N. (2013) compiled an extensive, well conducted FMEA related literature review in 2012, however the review did not identify publications that strictly focused on the *process* of developing a FMEA from inception to completion of the final document. The majority of the review identified and categorized the many proposed alternate methods to best calculate RPN values and/or reduce subjectively in the risk priority number (RPN) rating criteria and table. While this literature by Liu, et. al., (2013) review was comprehensive, the goal of this researchers literature review is to identify those alternate methods proposed by researchers that streamline the often tedious and time consuming process to develop either a DFMEA or PFMEA. This literature review is necessary and important because this researcher (Kluse, 2017) and others have noted shortcomings of the FMEA process that are unrelated to RPN calculation or the subjective nature of the severity, occurrence and detection criteria. Ganot (2015) asserted that "eventually, most often it (FMEA) becomes a form filling exercise to provide a deliverable document rather than a tool to focus on preventing problems and reduce risks" and "many companies do not have the requirements, neither the budget nor the time to conduct a classical FMEA". Netherton (2010) claimed, "while it's readily available and one of the most powerful tools in the Six Sigma toolbox, FMEA is one of the most misunderstood and most misused method". Lastly, in this researchers (Kluse, 2017) previous FMEA process investigation, it was concluded that "while the PFMEA can be a valuable tool, due to tedious development, vast and intricate guidelines, subjectivity, and complicated RPN's, the PFMEA method is not properly utilized or developed as suggested by current guidelines". Furthermore, this literature review will serve as validation (an identification of any new articles since 2012) of the Liu, et. al (2013) study and the results of this review will support the initial review and critique of the AIAG-VDA joint effort to standardize the FMEA development process.

1.2 FMEA –Description of the AIAG Methodology

A brief description of the AIAG FMEA process is as follows. Each constituent in the design process or each function in the manufacturing process is assigned a calculated risk priority number (RPN) thus relatively ranking risks in a component design or in component manufacture. The RPN values are the product of the severity value (S), occurrence value (O), and the detection value (D). Thus RPN = S x O x D. The severity, occurrence and detection values range from 1 – 10, where 1 represents minimal risk and 10 represents the ultimate risk for each category. Values from 1 – 10 are assigned by using the severity, occurrence and detection ranking tables outlined in Potential Failure Mode and Effects Analysis, 4th edition (2008). In addition to DFMEA & PFMEA development guidelines, the reference manual outlines the FMEA process (i.e. strategy) and offers several sample FMEA forms as well as appendices that suggest alternate approaches to risk assessment. These alternate methods (in the manual appendices) in part address some of the criticisms of the FMEA process outlined in the reference manual but further investigation and awareness of alternate FMEA development methods are needed. For illustrative purposes, a typical PFMEA is shown below:



Company	Failure Mode and Effects Analysis		FMEA Number Identification	Page of
Part Number (s) or Part Family	Design or Process Responsibility	Prepared by and their Title		Telephone # / Email Address
Process/Design	Team Members	FMEA Creation Date		Latest FMEA Revision Date

Process Step/Input or Design Item	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Process Controls to Prevent Failure Mode	Current Process Controls to Detect Failure Mode	DET	RPN	Recommended Actions	Person Responsible for Actions	Target Completion Date	Actions Taken	SEV	OCC	DET	RPN
									0								0
									0								0
									0								0
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									0								0
									0								0
									0								0
									0								0

Figure 1. Typical PFMEA Format

2. Literature Objectives & Review Methodology

2.1 Methodology

A systematic literature review was conducted using "EBSCO" and Summon. The Summon search included the criteria of "add results outside of your library's collection". EBSCO includes all EBSCO databases active in October 2017. A title search was conducted using the key term ***FMEA*** and a key phrase ***Failure Mode Effects and Analysis***. These 2 terms were combined with 6 key words to form the basis of the search; these words are *modified, revised, alternate* and *new approach*. Thus 12 exclusive searches per database were conducted using the following:

(1) FMEA & modified; (2) FMEA & revised; (3) FMEA & alternate; (4) FMEA & new approach; (5) FMEA & streamline; (6) FMEA & efficient/effective; (7) Failure Mode Effects and Analysis and modified; (8) Failure Mode Effects and Analysis and revised; (9) Failure Mode Effects and Analysis and alternate; (10) Failure Mode Effects and Analysis and new approach, (11) Failure Mode Effects and Analysis and streamline; and (12) Failure Mode Effects and Analysis and efficient/effective.

The literature search was de-limited to the time frame between January 1993 and November 2017 and was further limited to conference proceedings, peer reviewed and journal articles.

2.2 Literature Review Scope and Objectives

The intent of this literature review is to identify those researchers who have investigated and offered a solution to the tedious, often inefficient and ineffective FMEA development process. This review was not intended to identify revised or alternate severity, occurrence and detection tables found in the AIAG FMEA manual nor was this review intended to identify alternate methods to determine RPN values. This rationale comes from this researcher's 20 years spent as a quality professional in the automotive industry. Based on this experience, fundamental problems with poorly developed FMEA's are related directly to the *process and guidelines* to develop the FMEA. RPN's are extremely important, however it was not a significant contributor to developing a proper FMEA as defined by AIAG FMEA manual (2008). This rationale was documented in *Failure Modes and Effects Analysis (FMEA): Factors Affecting Execution and Implementation of the FMEA and an Alternate Method for Process Risk Assessment* (2017). For purposes of this study, **RPN determination** is defined by this researcher as *the acute method to calculate risk for a*

given process function and the **FMEA process** defined as *the collective group of cross-functional activities that ultimately lead to a development and maintenance of a living FMEA*. Research objectives include the following:

- Identify alternate methods/best practices that have been used/trialed in practice
- Address the tedious FMEA development problem that leads to "static" non value added FMEA's. Locate those articles that focus only on an efficient, revised FMEA process.
- Capture the published shortcomings of FMEA and not shortcomings of RPN determination

Using the above scope and research objectives the literature review was conducted. The results are presented in the following section.

3. Literature Review Findings

The EBSCO and SUMMON database were used with the key search terms identified in section 2 methodology. The results are summarized in figure 2.

Boolean	FMEA	Failure Modes Effect & Analysis
Modified	18	26
Revised	6	1
Alternate	0	0
New Approach	6	3
Streamline	1	0
Efficient/Effective	2	0
Total	33	30

Figure 2 – Literature Review Article Search Totals

The search resulted in 63 articles relating to a modified FMEA. After a review and analysis of the 63 articles, it was determined that 60 articles (95%) addressed the RPN aspect of the FMEA process. While this is a significant aspect of a FMEA and the FMEA process, it was not in the scope of this literature review. However, three articles or 5% of the total search are articles that address the problem of the FMEA process; these articles each offered unique methods to conduct and complete a FMEA all carrying the theme of a more efficient, effective FMEA process. These three articles are within the scope and intent of the literature review. The overall search can be broken down into five major FMEA themes, these are (a) expert involvement for RPN determination, (b) a new mathematical approach to determine RPN, (c) revised criteria and criteria weighting approach to determine RPN, (d) mixed approach using an expert and revised mathematical formula to obtain the RPN, and (e) systems or management approach to FMEA development. It was the latter category (three articles) that is the focus of this literature review; these are summarized in the subsequent section of this paper. With the exception of the "management" category, the main categories of FMEA articles summarized by this researcher aligned with the literature review conducted by Liu, et. al. (2013). Additionally, for those readers interested in a detailed breakdown of documented FMEA shortcomings, table 4 and appendix I in the Liu et. al. (2013) paper summarizes shortcomings found in 75 papers identified in these researchers 2012 literature review. What is important to note about the extensive list of shortcomings developed by Liu et. al. (2013) is that all of the documented shortcomings are predominantly related to RPN determination.

4. Review & Analysis of the Focus Articles

The 3 articles aligned with the scope of this literature review are (a) *Lean (and Friendly) FMEA* by Ganot, A. (2015), (b) *A Streamlined Failure Mode and Effects Analysis*, by Ford, E., Smith, K., Terezakis, S., Croog, V., Gollamudi, S., Gage, I., Keck, J., DeWeese, T., & Sibley, G. (2014) and (c) *Guidance for Performing Failure Mode Effects and Analysis with Performance Improvement Projects* by (CMS) the Center for Medicare & Medicaid Services (n.d.) These articles represent alternate FMEA development methods when compared to the AIAG manual, however this does not suggest these are the only alternate methods published and proposed, these are simply the articles identified using the literature review search criteria.

Ganot (2015) suggests an intuitive, 3 phase process to FMEA development. In the first phase of the process, a facilitator and subject matter expert lead a top down FMEA development activity. This differs from the classic AIAG approach that assembles a cross-functional team at the onset of the FMEA and uses this team throughout the entire FMEA development process. Ganot (2015) argues that the classic FMEA approach uses an inductive method that conducts analysis of possible component failure by evaluation of the effects on the system to assess fault. Ganot (2015) cites the main disadvantage of the classic (inductive) approach is the process is not effective in identification of "event combinations" i.e. redundancies, interactions, etc. Thus, it cannot be used to assess total system reliability. In the top down approach (deductive) the analysis begins by investigating/documenting unwanted systems failure and then determine the related components that may initiate the unwanted events. In the second phase, Ganot (2015) replaces the classic RPN method with a significant rank index (SRI) citing shortcomings of the classic RPN such as being difficult to remember and interpret RPN's and time consuming especially when it is a cross-functional team effort. The SRI has far less levels (RPN goes 1 to 1000) and uses easy to identify/recall human symbols. Figure 3 depicts Ganot's SR index.

Symbol	Failure Category	Criteria	Severity Rank
S	Safety	Failure may cause death	
CA	Catastrophic	Failure may cause severe injury or major system damage	
CR	Critical	Failure may cause minor injury or inability to perform mission	
MA	Major	Failure may cause degradation in mission performance	
MI	Minor	Failure does not influence system performance but may result in unscheduled maintenance	

Symbol	Failure Category	Criteria	Occurrence Rank
P	Probable	Failure will occur several times in the life of an item	
R	Remote	Unlikely but possible to occur in the life of an item	
I	Improbable	So unlikely it can be assumed failure may not occur	

Figure 3 – Ganot's SR Index

The final phase in Ganot's (2015) Lean FMEA suggests the use of an action summary table that aggregates and categorizes recommended actions in contrast to the classic approach where each line of the FMEA may (or should) receive a recommended action thus complicating and adding redundancy to the action priority process. While this process offered by Ganot (2015) may have some weaknesses, it does streamline the process, remove some of the tedious activities that lead to static FMEA's and would seemingly result in an effective, efficient FMEA. Examples of completed FMEA's would validate this assessment and process.

Ford et. al (2014) propose a structured process to develop a FMEA that will allow for minimization of resource and effort yet results in an effective, value added FMEA. These researchers document many

advantages and positive information regarding use of the FMEA, but question the practicality of the tools and FMEA process in an environment that is resource limited. Experience from within the researchers respective organization suggests a labor-intensive process taxing valuable resources. Ford et. al (2014) utilized a 4 step process for an external beam process in a radiation oncology center, with the strict intent of resource minimization. In each of the 4 sessions, a one-hour meeting (session) was conducted with each meeting having a clearly documented goal. In 3 of the 4 sessions, participants were given "take-home tasks" to complete as part of the FMEA development process. The sessions consisted of the following:

- Pre session by leadership to determine scope and group facilitator
- Generate process map and review example failure mode
- List failure modes without scoring
- Score failure modes (RPN) and rank failure modes
- Identify improvement for top ranked failure modes.

In addition to the process outlined above it is important to note that during this particular FMEA development project, the participants utilized a specific, customized table with criteria to determine severity (S), occurrence (O) and detection (d). The AIAG (2008) tables were not utilized to determine RPN values nor was the standard FMEA format used to develop a FMEA. The team identified 62 critical process steps and subsequently identified a total of 52 failure modes. An important aspect of this revised FMEA process is the method to obtain and identify the 52 failure modes. It was noted by Ford et. al. (2014), that 22 of the identified failure modes resulted from the second session in the process while 30 resulted from take home worksheets assigned to participants. Ford et. al., (2014) asserted that this was potentially an important aspect to comprehensive failure mode determination since participants may not always be willing to identify failure modes within a session or team (group) activity. This approach differs from that of AIAG where cross-functional participation is considered critical. Furthermore, after completion of the FMEA and implementation of corrective actions, the processes with the high RPN values were used as a source to validate the significance (or value) of the FMEA. In this validation exercise, a control group re-scored high RPN failure modes (4 selected) after intervention (actions) were implemented and the re-score by the control group suggested an improvement in the RPN of the chosen failure modes. This validation by a control group differs from the AIAG approach (validation is not outlined in the traditional FMEA process) and may promote an improved, effective, value added FMEA development process. In the traditional process, RPN's are re-evaluated after actions are implemented, however bias is often introduced as one assumes RPN has been reduced if actions are implemented. In practice this is not always the case, therefore a control activity or validation can remove this chance for bias and improve effectiveness of the FMEA process. Ultimately, the goal of developing and utilizing this alternate approach to FMEA was to reduce the time spent to complete the FMEA. Based on data collected from previous studies, Ford et. al. (2014) concluded that this FMEA process was an effective method to complete a value added FMEA without excessive exploitation of organizational resources. Not only did these researchers document that a FMEA can be effectively completed with only moderate use of resources, it was also demonstrated that a FMEA process can be streamlined to produce an effective, value added FMEA without some of the tedious requirements (FMEA forms, long meetings, etc.) of the traditional method.

The article, *Guidance for Performing Failure Mode Effects and Analysis with Performance Improvement Projects* by (CMS) (n.d.) represented a prescriptive method for developing a FMEA within a nursing home environment. As documented by the authors, much of this article content was originally found in three publications, these are, the *VHA National Patient and Safety Improvement Handbook*, (2011), the *Training Toolkit: Failure Mode and Effects Analysis* (2006) and the *Minnesota Adverse Health Events Measurement Guide* (2010). While this article did not focus on a specific problem, it did outline an alternate FMEA process that implies a streamlined approach over a traditional FMEA process. The steps to develop a FMEA in this process are:

Step 1 Select the process
Step 2 Select a facilitator and team members
Step 3 Describe/document the process
Step 4 Identify what could fail in each process step
Step 5 Determine which problems that require attention
Step 6 Develop and Implement actions
Step 7 Measure or validate the effectiveness of the actions

Some of the above steps are part of the traditional FMEA process, however a few noteworthy items help make this process less tedious and effective. In step 5, a team approach is used to determine which failure modes and/or processes will be addressed. In this step it is recognized that eliminating every possible failure mode is not feasible or necessary, thus the experienced team determines what will be the focus of improvement actions. The selection is not based on subjectively calculated RPN values derived from a table of criteria, but from the team's experience considering the following factors:

What is the outcome (effect of failure)?
What the nature of the outcome (severity)?
What is the likelihood of occurrence?

Thus the team approach eliminates the tedious RPN categorization/rankings and use of a complicated FMEA form as used in a traditional approach. An outcome severity-ranking table, shown in figure 3, with a simple scale from 1 (near miss) to 5 (catastrophic) can be used, however is not mandatory. It is noted that simple descriptive terms such as low, moderate, severe, or fatal can be effective as a scale (criteria based) ranking of outcomes. Using this approach, the decision to implement actions are generally focused on catastrophic, major and moderate issues thus eliminating noise from other less important failure modes that, in a traditional approach, hinder the FMEA development process due to subjective nature of ranking and RPN determination.

The method to document the FMEA and associated actions presented in this method also presents an efficient, effective approach to FMEA development. While there are advantages to the traditional FMEA form in figure 1, some (Kluse, 2017) cite this form as a barrier to completion of an effective FMEA. In the CMS (n.d.) method, the suggested FMEA documentation is in the form of a FMEA process improvement project (PIP) template. At first glance, it appears to be a bit lengthy, but as the major constituents of the template are evaluated, it is clear it is a simple tool to capture the entire process of FMEA development. It consists of team member identification, the process map, potential failure modes, and severity/likelihood of occurrence, a table of failures selected for action with a description of associated actions, and a table of implemented actions with identified measures of success. This template flows with the team actions and can be populated after each phase of the process thereby documenting all team actions (similar to simple meeting minutes) surrounding FMEA development in one robust document. Items such as root cause analysis, process flow chart and validation of effectiveness are enhancements over the traditional form and capture the total process and surrounding the FMEA and decision to implement actions. In the traditional FMEA process, the RPN is recalculated after the actions are implemented, however there is rarely and effectiveness measure used to evaluate, thus recalculated RPN's may or may not accurately reflect the reduction in risk of process improvement. Many times RPN's are arbitrarily lowered just because *some* action was taken, thus an objective method to measure the action effectiveness increases the integrity and value of the FMEA.

5. Conclusions & Future Considerations

Based on the three (3) focus articles identified in the literature review, several recommendations to improve FMEA integrity and efficiency surfaced, these are:

- Replace the existing RPN process with a streamlined process such as Ganot's (2015) Significant Rank Index (SRI). This will help expedite the FMEA process and simplify the ranking of failure modes.
- Utilize Ganot's (2015) categorical approach to listing the recommended actions. This removes the tedious and often subjective line-by-line approach to identifying and acting upon recommended actions as seen in the classic AIAG FMEA.
- The initial FMEA creation process should begin, and be lead by, a subject matter expert (SME). This replaces the initial use of a cross-functional team to develop the FMEA. While there are clear benefits of utilizing a cross functional team, using the SME initially helps advance the FMEA process and may improve the technical accuracy of the document before the document is handed off to a cross functional team for further development and evaluation.

Allow team members who are developing a PFMEA to work independent of the team. In other words, allow the team member alone time, or according to Ford et. at (2014) assign "homework" to the individuals to further identify and list potential failure modes. It was noted that this approach (independent vs. team) resulted in a robust and comprehensive generation of failure modes.

As suggested by the CMS (n.d.) replace the sometimes subjective and complicated RPN calculation with simple descriptive terms such as low, moderate, severe and fatal. In conjunction with this approach, do not react to every failure mode, but use a team consensus approach to determine which failure modes take priority and require corrective or preventative actions.

The FMEA is an integral part of a Quality Management System and is one of the best-known methods to assess risk, identify potential failure opportunities, and prioritize improvement actions. However, over the years, one of the most popular methods (AIAG) has received criticism ranging from problems with RPN calculations to subjectivity of the ranking criteria. While the process is effective, many researchers and practitioners have offered alternative methods to improve the FMEA process and increase FMEA effectiveness and accuracy. This literature review focused on those alternate methods that could improve the FMEA development process to assure FMEA's are completed accurately and timely. Three articles with a novel approach were reviewed and highlights of each article presented. Certainly these methods are not the only alternate methods posed, but are the 3 uncovered within the scope of this literature review. As technology progresses at a high rate, and complexity of systems are amplified, the increased potential for failure (in any discipline) cannot be ignored. Automotive recalls, batteries exploding, lawsuits for health care practices gone wrong and e-coli bacteria in food are just some examples where a FMEA can reduce the potential for failure. By improving the FMEA process, engineers, designers, etc can have increased confidence in products and processes thereby reducing risk of failure. Alternate methods to FMEA development are needed; this literature review has highlighted a few for consideration. Future considerations for FMEA research should place an emphasis on the soft skills and the organizational culture that is necessary to support a robust FMEA process. As documented in this research, there are many excellent alternatives to the AIAG FMEA method, however these methods are technical in nature and are complicated. As seen in previous research (Kluse, 2017) this can be a barrier to accurate and effective FMEA development. What is needed is a standardized, revised FMEA development method that has the necessary rigor to assess risk and identify potential failure, yet be conducive to development (not to complicated or tedious) of a complete, accurate and dynamic (living) FMEA. This can, and will help reduce risk and eliminate failure in almost all industries.

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A Review of Current Implementations of Statistical Process Control in Large Organizations

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Abstract

In 1931, Walter Shewhart introduced his work in statistical process control (SPC) through his book, Economic Control of Quality of Manufactured Product. A common confusion in the use of SPC is that it does not fit every business or industry. Since Shewhart's work was published, various companies and industries have implemented such practices as a method to control their manufacturing quality of product, service quality and design quality. The purpose of this investigation is to understand why some larger companies have yet to take advantage of the benefits of SPC. A preliminary survey was utilized to understand the extent by which SPC techniques are currently applied in large organizations. The results coupled with a description of the reported benefits and implementation barriers are presented. Finally, directions for future research are suggested.

1. Introduction

When Dr. Walter Shewhart first developed Statistical Process Control (SPC) techniques, his intent was to help improve the quality of Western Electric's telephone hardware. Statistical process control (SPC) is an integral part of monitoring, managing, maintaining and improving the performance of a process (either manufacturing or service) through the effective use of statistical methods (Antony & Taner, 2003).

When discussing SPC, we associate the concept with control charts. A control chart is a statistical tool used to study and control repetitive processes (Duncan, 1952). An example of an $\overline{X}$ control chart can be seen in figure 1 (the range chart has been left off for demonstration purposes only). Common elements of a control chart include control limits, process average or centerline and a time sequence of sampled or individually measured key characteristics in a process. These points represent variable or attribute data

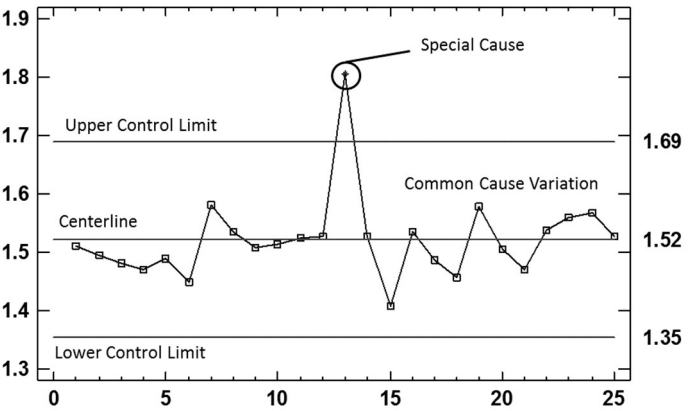

Figure 1. Example Control Chart

which drive the use of a specific type of control chart; one size does not fit all. Shewhart control chart

limits are calculated at three standard deviations from the process centerline which contain the natural or common cause variation in a process. Any points that fall outside of these limits are referred to as exceptional or special cause variation. The benefit of a chart allows the user to quickly identify a special cause point so that it can be investigated and corrective actions can be made to bring the process back into control. Additionally, when common cause variation in the process occurs, the user can limit the amount of reaction to changes in the measurements. In simpler terms, the control chart is an alarm system for detecting unwanted changes in a process.

Sampling inspection techniques made SPC popular by the military after World War II and again in the 1980s. Due to Japan's high quality output of products, the semiconductor and automotive industries adopted the techniques as a formula for remaining competitive in the world market. Rao (1989) stated: "It is not surprising that a recent book on modern inventions lists statistical quality control as one of the technological inventions of the past century. Indeed, there has rarely been a technological invention like statistical quality control, which is so wide in its application yet so simple in theory, which is effective in its results yet so easy to adopt and which yields so high a return yet needs so low an investment."

Professional experience and personal observations of this author through multiple quality management system audits and visits to aerospace manufacturers have shown that a gap exists in the industry with respect to the use and implementation of SPC methods and techniques. It is unclear when the aerospace industry first incorporated SPC techniques into their organizations. Speculation suggests that it occurred during World War II when aircraft production volumes were at its peak requiring standard techniques to maintain quality standards. Regardless of the implementation starting point, several quality management system industry standards, such as AS9100 Revision D and ISO 9001:2016, which are commonly used among aerospace organizations, have incorporated recommendations for the use of statistical process control as a method for establishing product or service acceptance. Even with industry standard recommendations, the use and implementation of these quality techniques appear to show a decline in use and application.

This investigation is to understand why some larger companies have yet to take advantage of the benefits of SPC. For the purpose of this study, the author has defined large organizations to include $50 million in revenue or greater.

2. Literature Review

A great deal of research has been done in the general area of statistical process monitoring (Woodall & Montgomery, 2014). It is not practical to review every paper or book on the subject, so a different approach was taken to review the trends and publications on SPC in an attempt to understand its health in industry.

Table 1 illustrates the evolution of SPC as researchers, academics and organizations discovered new uses and refined techniques for different conditions encountered in service and production. It may be important to note that during the 70s and early 80s, SPC growth was stagnant due to design of experiments having a larger focus in quality circles.

Table 1. Influential points in history that have or are affecting SPC

Year	Discovery	Sources*
1924	W.A. Shewhart introduces the control chart concept in a Bell Laboratories technical memorandum.	
1931	W.A. Shewhart publishes Economic Control of Quality of Manufactured Product – outlining statistical methods for use in production and control chart methods.	(Shewhart, 1931)
1940	The US War Department publishes a guide for using control charts to analyze process data.	
1942-1946	Training courses on statistical quality control are given to industry; more than 15 quality societies are formed in North America.	
1946	The American Society for Quality Control (ASQC) is formed as the merger of various quality societies. The International Standards Organization (ISO) is founded.	
1946-1949	Deming is invited to give statistical quality control seminars to Japanese industry.	
1947	Multi-variate control charts introduced	(Hotelling, 1947)
1950	Deming begins education of Japanese industrial managers; statistical quality control methods begin to be widely taught in Japan.	
1950s	Classic texts on statistical quality control by Eugene Grant and A. J. Duncan appear.	
1954	British statistician E.S. Page introduces the cumulative sum (CUSUM) control chart.	(Page, 1954)
1959	S. Roberts introduces the exponentially weighted moving average (EWMA) control chart. The U.S. manned spaceflight program makes industry aware of the need for reliable products; the field of reliability engineering grows from this starting point.	(Roberts, 1959)
1960s	Courses in statistical quality control become widespread in industrial engineering academic programs.	
1987	ISO publishes the first quality systems standard. Motorola's Six Sigma initiative begins.	
1988	The Malcolm Baldridge National Quality Award is established by the U.S. Congress.	
1995	Many undergraduate engineering programs require formal courses in statistical techniques, focusing on basic methods for process characterization and improvement.	
1997	Motorola's Six Sigma approach spreads to other industries.	
1997	The American Society for Quality Control becomes the American Society for Quality attempting to indicate the broader aspects of the quality improvement field.	(The ASQ Timeline, 2018)
2000s	ISO 9000:2000 standard is issued. Quality improvement activities expand beyond the traditional industrial setting into many other areas, including financial services, health care, insurance and utilities.	
2010 – current	Trends in use of control chart techniques increased in Healthcare	(Woodall & Montgomery, 2014)
2011	Industry 4.0 Concept Introduced	(A Brief History of Industry, 2017)

*Table adapted from (Montgomery, 2013) – additions were made, and sources noted for those not contained in the original source.

Table 2 is a result of utilizing a search process for publications containing topics of interest. A scholarly search engine which encompasses several databases was given a Boolean string of terms along with a date range and then a count taken of the publications that were found. The search (performed during the month of March 2018) was limited to publications in English, full-text, peer-reviewed and published since 1931 following the release of Shewhart's work on control charts. The following Boolean string was utilized, where *XYZ* is the term in the first column of *Table 2*:

TX Statistical Process Control AND TX Application AND TX Implementation AND TX XYZ

While it appears that SPC research is active and continues to grow in multiple areas, this review was unable to correlate publication terms "application and implementation" with actual industry application. It would require specifically looking at each publication to see if it was generated following an actual application within a company or industry. Because most quality practitioners lack access to the most useful mathematical results from theoretical studies (Woodall & Montgomery, 2014) (Woodall W. H., 2000) (Stoumbos, Reynolds, Ryan, & Woodall, 2000), the belief is that most publications are from research and academics and not real-world industry application.

Table 2. Search results by decade and term combination

	Decade									Totals		Grand Total
Term	30s	40s	50s	60s	70s	80s	90s	2000s	2011-2018	1931-2000	2001-2018	1931-2018
P-charts	3	24	139	483	1045	2646	13240	32811	53455	17580	86266	103846
C-charts	3	22	134	453	992	2478	12384	31194	51093	16466	82287	98753
X S Chart	2	15	79	315	716	1693	6846	19054	34555	9666	53609	63275
X R Chart	2	15	81	316	708	1684	6700	18174	32787	9506	50961	60467
Economic Control Chart	0	23	118	347	675	1422	7460	17391	27006	10045	44397	54442
U-charts	3	18	113	360	685	1631	5638	14453	26103	8448	40556	49004
EWMA	0	0	0	2	2	28	2344	14756	25558	2376	40314	42690
X MR Chart	2	10	41	107	190	396	1063	3686	6718	1809	10404	12213
CUSUM	0	0	0	0	9	62	284	1017	1677	355	2694	3049

Shewhart's SPC charts were intended to be simple and effective when analyzing data from real-world processes (Wheeler, 2004). When reviewing journals and publications from the technical community, it can be difficult to see the simplicity found from his original work. Most researchers adopt a case study approach versus application in a real-world situation and therefore can only offer indeterminate reflections on their findings (Srikaeo & Hourigan, 2002). As stated by Crowder et al. (1997) and quoted by Woodall (2000), "There are few areas of statistical application with a wider gap between methodological development and application than is seen in SPC." Industrial statistics were not developed for scientific research; they were meant for application in industry (Jones-Farmer & Stevens, 2017).

The author is aware of the associated sampling errors; however, the magnitude and general trend of publications can be utilized to show where research is being performed and which topics are the most active. Additional limitations to this search process exist. For example, publications were not reviewed for content; it would therefore be unclear whether a particular article contained applicable content to the subject searched or just merely contained the terms.

The author's experience in industry shows that practitioners are less interested in publishing actual application of the methodology and more interested in the outcome of the application. Some companies also limit publications for proprietary reasons. This makes it difficult to find publications with examples to use as guidance material and may result in the use of consultants and software packages. This does not always provide the underlying assumptions and knowledge base needed to know if SPC charts and methods are measuring the process correctly.

3. Preliminary Survey

Uncovering the answer on the prevalence of SPC utilization in industry requires some method of data collection. Businesses and researchers across all industries perform surveys to help answer specific questions where data cannot easily be gathered without being onsite at a facility. For this study, both demographic and open-ended questions were built and distributed to the recipients. The intent of the survey was to pull together enough information to validate and understand the state of SPC in industry.

4. Results

The following section contains the questions asked and the responses that were provided from the participants in this initial study. Revenue dollars was chosen as a metric to segregate companies that may claim they do not have resources available to handle an SPC implementation. Survey respondents were then chosen based on an affiliation with an industry wide quality society to help ensure companies that participated would understand the terminology being applied in the survey.

Fifty-one companies were chosen based on their revenue and association and the survey was conducted anonymously. Unless the respondent chose to identify themselves, we are unable to link the industry to specific responses.

4.1 Response Rate

14 out of 51 companies participated in the survey for a response rate of 27.5%.

4.2 Do you use SPC Charts?

Next we need to understand if they know what SPC charts are, and if they utilize them within their business. Four out of 14 respondents stated they know what SPC is but did not currently utilize it within their business. The other 11 gave responses that some form of SPC charting was utilized in their facilities. Of the 4 that responded negatively, the comments gave a clue that there may have been a possible implementation of SPC, but was later abandoned.

4.3 Who owns and implements the SPC process within your company?

Once we have established the use of the SPC methods, we wanted to know who or what organizations owned and implemented the process. Multiple organizations within a company were allowed to give a response. Figure 2 is a bar chart of the organizations involved.

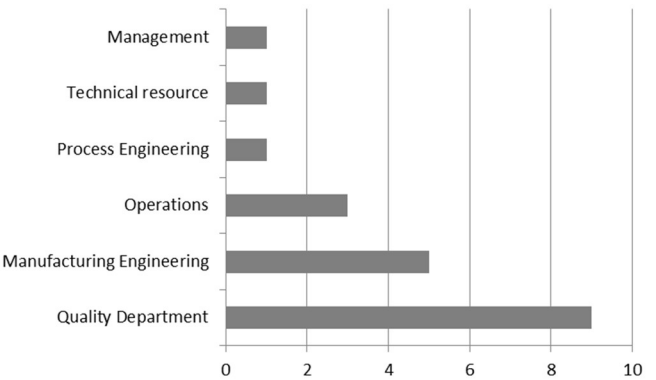

Figure 2. Implementation Ownership

4.4 Where SPC Charts are applied?

Knowing who is responsible, we next wanted to understand where SPC is applied. Figure 3 illustrates the areas where SPC methods and techniques are utilized.

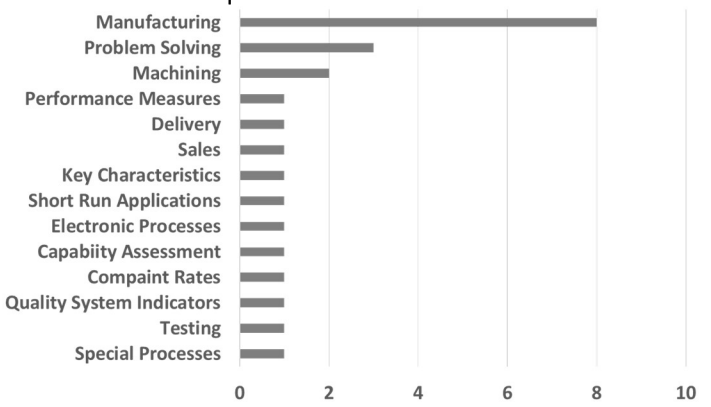

Figure 3. Implementation Ownership

4.5 What type of parameters are measured?

Knowing the 'Who' behind the SPC techniques, we now want to know 'What' is being measured. Comments were categorized into three types of parameters: inputs, outputs and a combination of both inputs and outputs. Examples of an input might be a chemical concentration that is needed to provide a specific coating thickness. An output might be a defect rate for a process. At times, test results can be either an input needed for the process or the final output or result of a process. Results are shown in Figure 4.

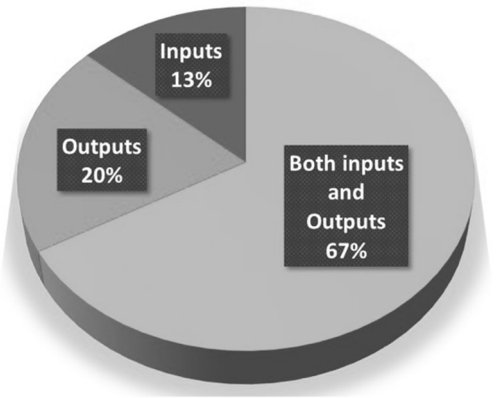

Figure 4. Categories of parameters measured

4.6 Do you utilize an off the shelf software package, home-grown or combination of the two?

Understanding why some companies are not utilizing SPC techniques can sometimes be found in the software or data capture methods which aid the user in analysis and tracking. If it is difficult to use, then employees find ways to stop performing the function. This question resulted in 25% of the companies use a homegrown package, 33% utilize off the shelf programs and 42% use a combination of both homegrown and off the shelf systems.

4.7 Why were SPC Charts chosen and what barriers were realized upon implementation?

The last two questions focused on why SPC methods were chosen and what possible barriers were recognized upon implementation in an area. The following is a list of the responses given. In summary, the top key reasons were performance measures, better decision-making and the ability to link production with the engineering design to validate manufacturability.

- Our organization realizes the importance of measuring success, failure and variation.
- You can't manage what you can't measure.
- Ability to compare process capability to design for potential design changes.
- More consistent decision-making.
- Early warning instead of late reaction.
- Product quality and process optimization were the main drivers.
- Process thinking for leaders.
- Need for controlling select precision operations.
- Reduce reliance on inspection.
- We realize that SPC data allows us to make informed and scientific decisions about our processes.

For those companies that were able to implement SPC, it is important to understand what barriers they had to overcome in order to implement SPC. For those that did not have current SPC implementations, we did not ask for a response about barriers because, without context, we were uncertain if the company had tried to implement the techniques or methods.

5. Conclusions and Remarks

Seven questions were asked of 51 companies with respect to SPC and its implementation within their business. While the survey response rate is typical for this survey size, it might be considered small compared to the number of businesses that exist world-wide. Given that 28.5% of those surveyed did not use SPC, there is a potential gap in implementation of SPC. They are not as widespread as one might expect, even supposing SPC is a simple and standardized form of process performance measurement which could lead to quality improvements over time. Because the survey was anonymous, it does not identify the specific industries not utilizing SPC; however, the author draws the conclusion that the aerospace industry is one that has a lower implementation rate based on physical evidence from on-site audits as mentioned in the introduction.

Gunter (1998) argues that control charts have lost their relevance and states that companies have moved beyond this "honored but ancient tool." Yet, companies that have implemented SPC provided remarks that are consistent with benefits described in other publications. It therefore has not lost its relevance; the issue is a result of deficiencies in other areas of implementation.

It has been noted from the survey that the "quality" department appears to drive or own more implementations than any other group. While they may have the expertise to implement and design the methods, it is the service providers and manufacturing organizations that utilize the processes that are being measured. Data gathering becomes a nuisance from a lack of buy-in to the process due to incorrect process ownership or lack of roles and responsibilities. Response to indicators of out of control processes may not occur in a timely manner or not at all, leading to poor quality products and potential escapes to the customer.

Six Sigma methods resurrected SPC charting methods as a formal way to analyze data and control process improvements, resulting from the analyze and control phases of a define-measure-analyze-improve-control (DMAIC) project. Six Sigma training in control chart methods covers high level application to processes and often relies on software tools for setup and analysis. Trainers and consultants do not spend time educating the lay persons in the assumptions and theories that go into the correct application

of a control chart. The missing information can lead to incorrect implementation of the tools and techniques, leading to false indicators and possible escapes of poor quality to their customer. The adoption of the incorrect methodology can lead to lack of success with SPC implementations (Antony & Taner, 2003). Antony and Taner further state that some companies even believe that control charting is a chart on a wall for satisfying customers.

One objective of SPC techniques are to catch issues in the process before creating defects. Shewhart's definition of control states that the process will be in control when utilizing past experience to predict the future performance of a characteristic within statistical limits. Survey responses point to the use of more measures of output than input. It is the predictive nature of a control chart when measuring inputs that provides the most benefit to the process. Controlling input measures allows one to guarantee an output within limits as long as only chance variation exists. If companies are focused more on output performance, it becomes problematic to control the process in order to prevent a defect. Control charts that measure outputs then become a reactive measure allowing poor quality until the process can be brought back into control. Based on the barriers to implementation, it appears that proper selection of key characteristics may be a gap in the implementation process and should be addressed to gain full benefits of SPC.

Key barriers to implementation involved lack of resources, lack of understanding of the techniques and its terminology, fear of statistics and management's understanding of quality and what the SPC toolset can provide as a benefit to the business. One comment that was not repeated but did validate what some authors of journal publications had stated was, "implementations in literature are not clear and make it difficult to transfer to real-world applications." Woodall's viewpoint (2000) states there needs to be a quicker transition from the classical methods to newer approaches when appropriate. This author would argue, based on this preliminary survey and personal observations, that implementations and correct use of control charts involves getting back to the basics and simplicity that Shewhart intended for industrial applications. When concepts become difficult and challenging to implement, humans surrender and revert to alternate means or hamper the new process from being successful.

6. Limitations

Surveys are not without limitations. This particular survey is limited to large organizations and associated with an industry quality society. There are other populations that may be of interest in understanding why companies do not or struggle to implement SPC. This survey also utilized open-ended questioning without follow-up or clarification of the responses submitted. Understanding context and situational awareness will give better insight into any gaps that may exist. Incomplete responses are limiting when the thought being conveyed is not clear and the analysis of the response could lead to an incorrect conclusion. The small sample size is a limiting factor. Sample size and demographics can influence results from one spectrum to another and might lead to false or incomplete conclusions.

7. Future Research

Advances in technology have continued to increase the amount of data available for analyzing of process performance. It is these large data sets or "big data" that will challenge the simplicity of statistical process control charting. Future studies should look in depth at the implications of Quality 4.0 which is interrelated to Industry 4.0 where reliance on digital sources and machines is more prevalent.

Data analysis can often be paralyzed by the software or tools used to analyze data. Exploration of resources that aid in SPC implementations should be reviewed to understand what characteristics are beneficial and could therefore be applied in companies that are struggling with SPC.

This initial study only begins to identify potential reasons why implementations have yet to occur in

businesses. Follow-on studies should expand the survey to include more detailed questions and possible follow-on interviews so that the context in which the answers are given is understood. Then one can take that information to help develop a framework for implementation in businesses that have yet to take advantage of the techniques. Any solutions should then be validated in an industrial setting and be less reliant on simulations and theoretical predictions.

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Enhancing the Mechanical Properties of HDPE Reinforced with Flax Fibers Composites during Injection Molding Process using Numerical Optimization

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Abstract

This research aided in enhancing the mechanical properties of the High Density Poly-Ethylene (HDPE) reinforced with 10%weight flax fiber composites by controlling the effect of injection molding process parameters. The effect of injection temperature on the Ultimate Tensile Strength (UTS) and toughness was studied at 170, 195 and 2200C. Moreover, the effect of injection speed on the UTS and toughness was studied at different values, 8, 50, and 125 mm /sec. While, the effect of screw speed on the UTS and toughness was studied at 75, 185, and 250 rpm.

The experimental results were recorded, analyzed and discussed for both UTS and toughness tests. The injection temperature, injection speed and screw speed and their higher order interactions were found to have a significant effect on both the UTS and toughness. Non-linear optimization was utilized to maximize both the UTS and toughness.

1. Introduction

Nowadays, ecological concern has resulted in a renewed interest in natural materials. Issues such as recyclability and environmental safety are becoming increasingly important for the introduction of new materials and products (Mohanty et al, 2005).

The composites based on natural fibers are more environmentally safe than synthetic fibers. During their life cycle, they use less energy and generate fewer air emissions compared to fiberglass composites. Moreover, production of glass fibers has a higher environmental impact than natural fibers. They are also expected to cause less wear to screws and tooling since they are not as abrasive as glass fibers (Benhadou et al, 2016; Mulinari et al, 2015; Goutianos et al, 2006). Also, high absorptive behavior which creates an excellent acoustics effect could be obtained by reinforcing a matrix with natural fibers rather than synthetic fibers (Saravanan, Dhurai, 2012). Furthermore, composites reinforced by natural fibers are lightweight and have high specific stiffness compared to those reinforced by glass fibers (Van de Velde, and Kiekens, 2003; Goutianos, and Peijs, 2003). Generally, the mechanical strength of the composite depends on the amount of reinforcing elements either synthetic or natural (Shaharuddin et al, 2006).

Benhadou et al (2016); Akerholm et al (2003); Askargorta et al (2003); Assouline et al (2000) have reported that natural fibers such as flax, hemp, palm, jute, banana, bamboo, cotton, wood, jute, kenaf, sisal, were studied to reinforce polymers. According to Strong (2006), Polymeric composite materials represent about 90% of all composites. These composites are being used in automotive applications, construction as well as packaging industries (Daniella et al, 2015).

Barkoula et al (2010); Bos et al (2002) have informed that flax fibers have very high tensile strength compared to other natural fibers. The value of tensile strength is up to 1500 MPa for elementary fibers

and about 800MPa for technical fibers, which are basically bundles of elementary fibers.

High density polyethylene HDPE is undoubtedly one of the best candidates as a matrix material for natural fiber-reinforced composites. This is due to its low price, its low melting temperature which is below the thermal decomposition temperature of natural fibers. Also, a considerable cost reduction during composites production is obtained due to low melting temperature of HDPE.

Barkoula et al (2010); Turng et al (2001) have informed that about 32% by weight of all polymeric materials processed are produced with complex geometries and various sizes by an injection molding technique. Transportation, marine, building/construction, electrical/electronic and consumer products are the main fields in which growth is taking place. Not only the polymeric materials could be produced by this technique but also the polymeric composite materials reinforced with fibers such as glass fiber or natural fibers like flax could be produced.

On the other hand, many researches on natural fiber composites have been carried out to evaluate their mechanical behavior. These composites were mainly fabricated with conventional hot pressing, although injection molding is a productive method. This may be attributed to its process parameters having not received enough study (Shibata et al, 2010). Hence, controlling the injection molding process parameters is required (Benhadou et al, 2016; Kavade and Kadam, 2012; Ozeelik et al, 2010).

These process parameters include melt temperature, injection pressure, injection speed, injection time, filling time, mold shape, mold temperature, material properties, etc. These process parameters affect the quality of injection molding products. For example, faster injection speed is usually applied to achieve products with better surface finish. It is recommended that a higher injection speed, pressure, mold and melt temperature be used during processing to get a glossy surface finish (Shaharuddin et al, 2006).

The injection molding process parameters have an effect on the mechanical properties of polymers and polymeric composites. Impact strength of polypropylene increased with the increase of injection pressure and decreased with the increase of injection temperature and cooling time. Also, there is no significant effect of screw speed and injection speed on the impact strength of polypropylene (Adilson Veiga et al, 2005). On the other hand, impact strength jute/polypropylene composites increased with the decrease of injection temperature (Saravanan and Dhurai, 2012). Flexural strength, flexural modulus and absorption energy of bagasse/polypropylene injection molding composites decreased with the increase of injection temperature (Shibata et al, 2010).

This paper intends to study the effect of changing injection molding process parameters on the ultimate tensile strength (UTS) and impact strength of flax reinforced HDPE composites. These parameters are injection temperature, injection speed and screw speed.

Injection temperature is a temperature at which molten metal is injected to the mold. Injection speed is a forward speed of the screw during its injection operation while screw speed is the rate at which the screw rotates.

The paper consists of four more sections that shows the experimental work; experimental data collection; data analysis and discussion; optimization model. This is then followed by the conclusions and references.

2. Experimental work

This section is composed of four sub-sections. Through these sub-sections, the authors illustrate information regarding the materials used in the experiment; how the composite is prepared; how the samples are prepared for the experiment; and finally the mechanical tests used.

2.1. Materials

The matrix is injection molding grade M300054 high density polyethylene HDPE. The polymer granules were supplied from a Saudi Polymer Company. HDPE granules were oven dried at 80℃ for 24 hours. The density of HDPE at 23℃ is ρ = 954 Kg/m^3, Vicat softening temperature = 121℃ and melt flow rate at 190℃ and 2.16 kg is I = 30g/10 min.

2.2. Composite preparation

About 10% wt. of dried flax fibers are mixed with 90% wt. dried HDPE granules in the extrusion machine. (TSK - 35 parallel Twin -screw extruder) as show in Figure (1). The mixing process was performed at 180°C and 10 rpm screw rotational speed. The extruded composites were pelletized into pellets of 3 mm length then dried at 80 ℃ and 48 h.

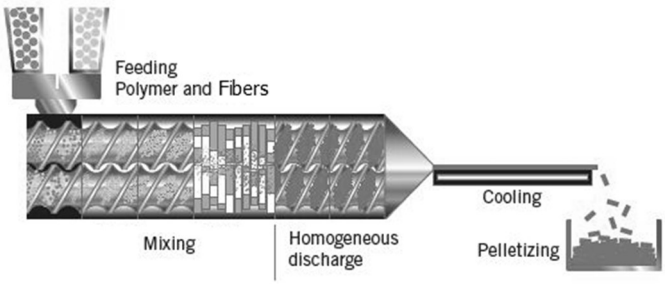

Figure 1. The production of Flax-HDPE composite pellets

2.3. Sample test preparation

The tensile samples were produced using an injection molding machine (injection molding machine No FT06205 model FT- 60~FT-600) according to DIN. ISO 527.2 standard. Pellets were injected to tensile samples under different injection parameters. The injection temperatures were 170, 195, and 2200C. Also, the values of injection speed were 8, 50, and 126 mm / sec. Moreover, the screw speed values were 75, 185, and 250 rpm. Back pressure and cooling time were kept constant at the value of 40 kg/cm2 and 40 seconds respectively. All of the above samples undergoes mechanical tensile test (as shown in Sub-section 2.4) and the ultimate tensile strength and the toughness was recorded for each sample. Data are collected and analyzed in Section 3 below. It should be noted that the lowest temperature is coming from the materials data sheet, the maximum temperature choice avoided reaching the decomposition temperature of the material. It is worth saying that the literature most commonly used these levels of process parameters. In addition, the screw speed and injection speed was chosen as percentage of the machine conditions

2.4. Mechanical tests

The tensile test was carried out according to DIN EN ISO 527-2 standard using 5 kN universal testing machine Lloyd LRX-Plus with cross head speed 5mm/min. Two response factors were measured as an output of the experiment namely ultimate tensile strength and toughness.

3. Experimental data collection

Data for ultimate tensile strength and toughness are collected from the samples prepared in Section 2 are undergoing mechanical testing according to DIN EN ISO 527-2 standard. The collected data is shown in Table (1) below. The experimental design used is 33 (three factors each at three levels), each combination replicated 2 times. The design factors are injection temperature; injection speed; and screw

speed. The total number of runs are 54, and the experiment was performed with complete randomization, no severe problem was encountered during the experiment except for the fibers preparation to ensure proper accurate dimensions. In each run, the ultimate tensile strength and the toughness were recorded as shown in Table (1). This data was then entered into Design Expert V9 software to perform the analysis.

Table 1. Experimental data for UTS and toughness

Run	Injection Temperature	Injection Speed	Screw Speed	UTS	Toughness	Run	Injection Temperature	Injection Speed	Screw Speed	UTS	Toughness
1	170	75	8	14.863	6.6533	28	170	75	8	14.8964	6.89
2	195	75	8	16.595	8.2367	29	195	75	8	16.75	8.8191
3	220	75	8	16	2.707	30	220	75	8	16.25	3.198
4	170	187	8	16.694	9.037	31	170	187	8	16.34	9.1113
5	195	187	8	14.962	6.0313	32	195	187	8	15.071	6.78
6	220	187	8	15.605	7.578	33	220	187	8	15.44	9.04
7	170	250	8	15.95	8.52	34	170	250	8	15.85	9.86
8	195	250	8	14.894	5.2294	35	195	250	8	14.974	5.272
9	220	250	8	15.63	6.88	36	220	250	8	15.58	6.92
10	170	75	50	16.096	7.436	37	170	75	50	16.0341	7.485
11	195	75	50	15.435	6.821	38	195	75	50	15.482	5.676
12	220	75	50	15.7	3.898	39	220	75	50	15.87	4.23
13	170	187	50	17.143	9.35	40	170	187	50	16.83	8.472
14	195	187	50	15.8	8.458	41	195	187	50	15.745	8.51
15	220	187	50	15.468	11.06	42	220	187	50	15.39	9.44
16	170	250	50	16.31	9.33	43	170	250	50	16.64	9.56
17	195	250	50	15.496	5.641	44	195	250	50	15.78	5.175
18	220	250	50	14.7	8.312	45	220	250	50	15.06	9.52
19	170	75	126	15.35	7.69	46	170	75	126	15.36	7.32
20	195	75	126	15.502	5.7354	47	195	75	126	15.66	6.357
21	220	75	126	16.122	6.1322	48	220	75	126	15.96	6.38
22	170	187	126	16.56	6.34	49	170	187	126	16.313	6.216
23	195	187	126	15.38	7.02	50	195	187	126	14.8226	7.21
24	220	187	126	14.5	4.274	51	220	187	126	14.198	5.65
25	170	250	126	17.382	10.321	52	170	250	126	17.484	8.255
26	195	250	126	16.204	5.978	53	195	250	126	16.394	5.54
27	220	250	126	13.235	2.23	54	220	250	126	13.2	4.293

4. Data analysis and discussion

The collected data was entered into Design Expert 9.0.6 software for analysis. The two response factors ultimate tensile strength and the toughness was studied to find the influential factors (using ANOVA) that affects each of these response factors. The analysis consists of ANOVA analysis to highlight the influential process factors that significantly affect the response factors (UTS and toughness); the residual analysis to ensure that the ANOVA assumptions are valid; the regression mathematical models that formulate equations for the response factors in terms of the process influential factors; and finally the model plots that graph the response factors as a function of the process influential factors. This analysis is repeated once for each of the response factors.

4.1 Ultimate tensile strength

Data for the ultimate tensile strength for the 54 runs was analyzed using Design Expert 9.0.6. Software. The results of the analysis is shown below. Note that all analysis inferences are based on a significance level of α= 0.05. This section utilizes the P-value technique to judge significance due to simplicity of use. If P-value < α, then the factor effect is significant.

4.1.1. Analysis of variance:

Analyzing this factor revealed that no simple model was satisfying in explaining the variability in the data and that most of the higher three factors interactions and some quadratic combinations of factors were found to be significant and thus included in the model. The authors of this paper decided to include higher factors interactions due to its significance in the model. Any attempt to reduce the model further and ignore higher order interaction results on the lack of fit being insignificant which means that these interactions can't be ignored and should be included in the model. Thus the resulting model is shown in the Analysis of Variance (ANOVA) table below (Table 2).

Table 2. Reduced ANOVA for the UTS

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	38.58	25	1.54	64.33	< 0.0001	significant
A-Temperature	3.80	1	3.80	158.25	< 0.0001	
B-Screw Speed	0.32	1	0.32	13.22	0.0011	
C-Injection Speed	0.070	1	0.070	2.91	0.0990	
AB	1.10	1	1.10	45.77	< 0.0001	
AC	0.11	1	0.11	4.67	0.0394	
BC	3.02	1	3.02	125.75	< 0.0001	
A^2	0.18	1	0.18	7.65	0.0100	
B^2	0.052	1	0.052	2.15	0.1538	
C^2	0.45	1	0.45	18.90	0.0002	
ABC	2.81	1	2.81	117.22	< 0.0001	
A^2B	0.53	1	0.53	21.92	< 0.0001	
A^2C	0.044	1	0.044	1.81	0.1888	
AB^2	0.26	1	0.26	10.78	0.0028	
AC^2	0.55	1	0.55	23.07	< 0.0001	
B^2C	0.10	1	0.10	4.24	0.0488	
BC^2	0.71	1	0.71	29.45	< 0.0001	
A^2B^2	0.022	1	0.022	0.93	0.3423	
A^2BC	3.16	1	3.16	131.74	< 0.0001	
A^2C^2	0.024	1	0.024	1.01	0.3244	
AB^2C	0.83	1	0.83	34.39	< 0.0001	
ABC^2	0.72	1	0.72	29.81	< 0.0001	
B^2C^2	0.66	1	0.66	27.42	< 0.0001	
A^2B^2C	3.428E-004	1	3.428E-004	0.014	0.9057	
A^2BC^2	0.75	1	0.75	31.39	< 0.0001	
A^2B^2C^2	0.24	1	0.24	9.85	0.0040	
Residual	0.67	28	0.024			
Lack of Fit	0.025	1	0.025	1.03	0.3184	not significant
Pure Error	0.65	27	0.024			
Cor Total	39.26	53				

By checking the residual plots, it is found to be independent and to follow a normal distribution with constant variance. Thus, the ANOVA assumptions were confirmed. Therefore, it is acceptable to use the model in discussing the effects of the controllable factors on the response factor.

It is worth saying that the lack of fit in the model shown in Table (2) was not significant which confirm that fact that no significant factors were excluded from the model and that the above model can be used accurately to discuss the design space.

4.1.2. The regression model:

The regression model is an expression of the response factor in terms of the significant effect factors. The obtained model shown in Table (2) above results in a correlation coefficient (R2) of 0.9829 which confirms that this model is an excellent model to explain the variability of the data and that there is no other significant factor missing from the model. A regression model that illustrate the relationship between the process influential factors (injection temperature; injection speed; and screw speed) with their interactions and UTS (response factor) is generated to be used for prediction purposes to predict Computer software can assist sometimes in computations taking into consideration that all attempts to reduce the model terms to enhance its simplicity failed drastically.

4.1.3. Response surface and contour plots:

The design expert software aids in the generation of both the response surface and the contour plots using the equation generated in Sub-Section 4.1.2 above. Both graphs (Figure 2) illustrate how to maximize the UTS of the HDPE Reinforced with Flax Fibers Composites during Injection Molding Process. The graphs show that the UTS increase when we increase the screw speed and reduce the injection temperature. These plots are done at maximum injection speed (which give maximum UTS, when injection speed is reduced, UTS decreases). Thus, to maximize the UTS of the composite, we should increase injection speed and screw speed and reduce injection temperature.

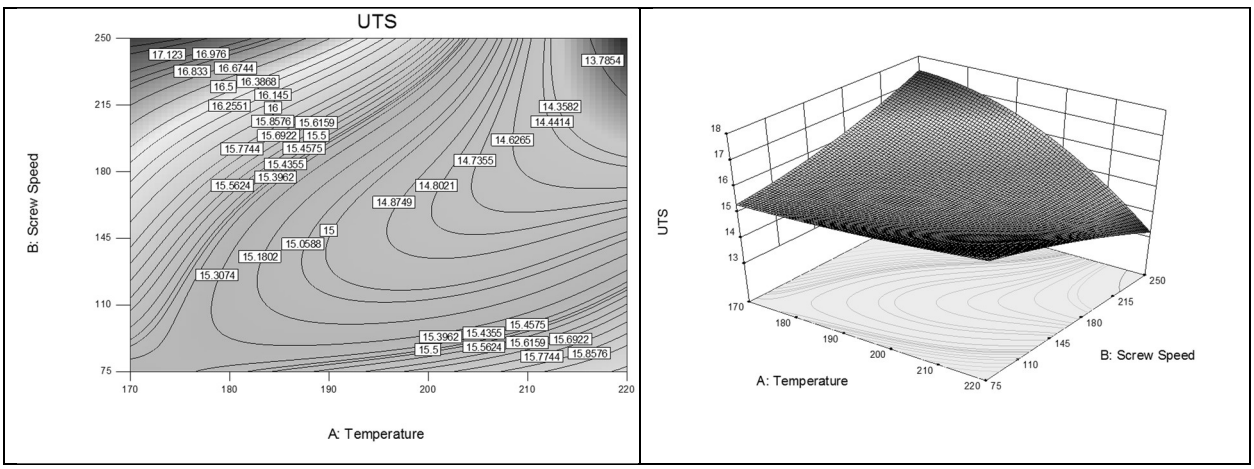

Figure 2. Response surface and contour plots for the UTS

4.2 Toughness

Data for the toughness measurements for the 54 runs was analyzed using Design Expert 9.0.6. Software. The results of the analysis is shown below. Note that all analysis inferences are based on a significance level of α= 0.05. Again, this section utilizes the P-value technique to judge significance due to simplicity of use. If the P-value is < α, then the factor effect is significant.

4.2.1. Analysis of variance:

Analyzing the toughness of the composite revealed that most of the higher three factors interactions and some quadratic combinations of factors were found to be significant and thus included in the model. The authors of this paper decided to include higher factors interactions due to its significance in the model. Any attempt to reduce the model further and ignore higher order interaction results on the lack of fit being insignificant which means that these interactions can't be ignored and should be included in the model. Thus the resulting model is shown in the Analysis of Variance (ANOVA) table below (Table 3), and the lack of fit was not significant which confirm the fact that no significant factor was excluded from the model.

Table 3. Reduced ANOVA for the toughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	194.62	22	8.85	20.83	< 0.0001	significant
A-Temperature	*1.66*	*1*	*1.66*	*3.90*	*0.0572*	
B-Screw Speed	*0.049*	*1*	*0.049*	*0.12*	*0.7357*	
C-Injection Speed	*0.053*	*1*	*0.053*	*0.12*	*0.7273*	
AB	*2.28*	*1*	*2.28*	*5.38*	*0.0272*	
AC	*0.12*	*1*	*0.12*	*0.28*	*0.5973*	
BC	*4.63*	*1*	*4.63*	*10.91*	*0.0024*	
A^2	*1.35*	*1*	*1.35*	*3.17*	*0.0848*	
B^2	*11.46*	*1*	*11.46*	*26.98*	*< 0.0001*	
C^2	*2.25*	*1*	*2.25*	*5.30*	*0.0282*	
ABC	*9.67*	*1*	*9.67*	*22.78*	*< 0.0001*	
A^2B	*19.45*	*1*	*19.45*	*45.81*	*< 0.0001*	
A^2C	*4.81*	*1*	*4.81*	*11.33*	*0.0020*	
AB^2	*13.74*	*1*	*13.74*	*32.37*	*< 0.0001*	
AC^2	*4.10*	*1*	*4.10*	*9.67*	*0.0040*	
B^2C	*0.78*	*1*	*0.78*	*1.83*	*0.1860*	
BC^2	*4.46*	*1*	*4.46*	*10.50*	*0.0029*	
A^2B^2	*1.11*	*1*	*1.11*	*2.62*	*0.1155*	
A^2BC	*15.92*	*1*	*15.92*	*37.51*	*< 0.0001*	
A^2C^2	*3.58*	*1*	*3.58*	*8.43*	*0.0067*	
ABC^2	*4.49*	*1*	*4.49*	*10.58*	*0.0028*	
B^2C^2	*4.31*	*1*	*4.31*	*10.15*	*0.0033*	
A^2B^2C	*5.94*	*1*	*5.94*	*13.98*	*0.0008*	
Residual	13.16	31	0.42			
Lack of Fit	*1.69*	*4*	*0.42*	*1.00*	*0.4259*	*not significant*
Pure Error	*11.47*	*27*	*0.42*			
Cor Total	207.78	53				

By checking the residual plots for the ANOVA of the toughness, it is found to be independent and follow the normal distribution with constant variance. Thus, the ANOVA assumptions were confirmed. Therefore, it is acceptable to use the model in discussing the effects of the controllable factors on the response factor.

4.2.2. The regression model:

The obtained model shown in Table (3) above results in a correlation coefficient (R2) of 0.937 which confirms that this model is an excellent model to explain the variability of the data and that there is no other significant factor missing from the model. A regression model that illustrates the relationship between the process influential factors (injection temperature; injection speed; and screw speed) with their interactions and Toughness (response factor) is generated to be used for prediction purposes to predict the toughness at any values of the process factors (injection temperature; injection speed; and screw speed).

4.2.3. Response surface and contour plots:

Response surface and the contour plots were generated through Design Expert 6.0.9 software using the equation generated in Sub-Section 3.2.2 above. Both graphs (Figure 3) illustrate how to maximize the toughness of the HDPE Reinforced with Flax Fibers Composites during Injection Molding Process.

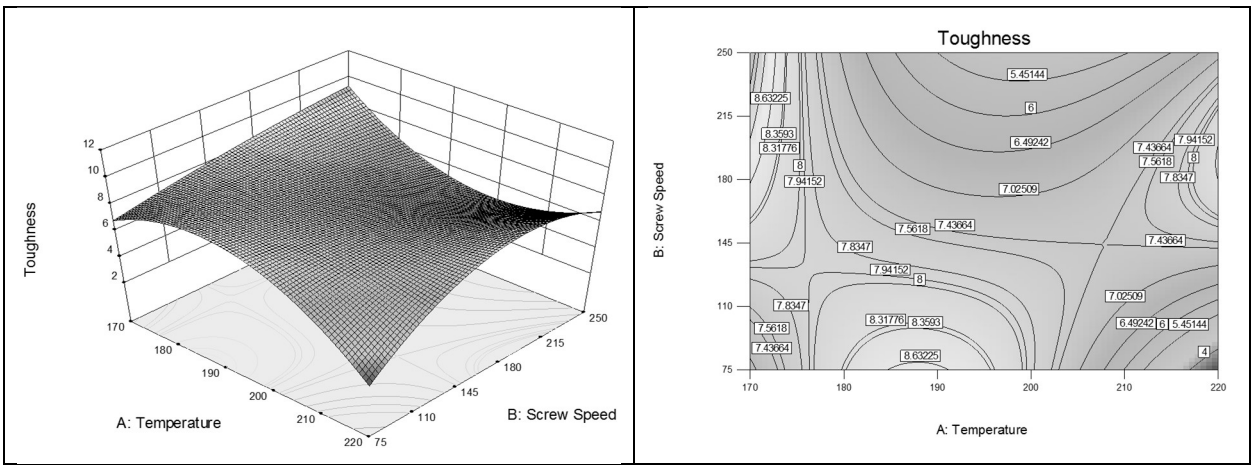

Figure 3. Response surface and contour plots for the toughness

The graphs show that the toughness increases when we increase the screw speed and reduce the injection temperature. These plots are done at a minimum injection speed (which give maximum toughness, when injection speed is reduced, maximum toughness decreases). Thus, to maximize the toughness of the composite, we should reduce injection speed and screw speed and reduce injection temperature.

5. Optimizing the mechanical properties of the HDPE reinforced with flax fibers composites

This section focus on the optimization of the mechanical properties of the HDPE Reinforced with Flax Fibers Composites namely UTS and toughness by controlling the process factors (screw speed; injection speed; and screw temperature). Equations (1) and (2) are numerically optimized to achieve the optimum solution that maximize both UTS and toughness. The optimization model will run as shown in Figure (4) below. Table (4) shows the output of this analysis. It is worth saying that in the below optimization model,

the author assumed that both UTS and toughness hold equal importance. This is denoted by the number of stars (*****). The (*) beside the objective function illustrates the importance of this function as compared to other objective functions. The UTS is measured to estimate the maximum resistance of the materials and also toughness depends on strength and strain. The case presented with respect to the importance (priority) of different response factors is just for illustration however in different other applications, the priority of the objective function could change.

Maximize UTS (*****)
Maximize Toughness (*****)
S.T.
170≤ Injection Temperature ≤ 220
75 ≤ Screw Speed ≤ 250
8 ≤ Injection Speed ≤ 126

Figure 4. The optimization model for the mechanical properties

Table 4. Optimization of the mechanical properties of the HDPE reinforced with flax fibers composites

Optimum Solution		**Process Factors Values to Achieve Optimum Mechanical Properties**		
UTS Mpa	**Toughness J/mm^3**	**Injection Temperature (^{o} C)**	**Injection Speed (mm/sec)**	**Screw Speed (rpm)**
17.445	9.266	170	126	250

If the composite manufacturer controls the process factors (Injection temperature; inspection speed; and screw speed) at the values shown in Table (4), maximum UTS and toughness for the composite will be achieved at UTS of 17.445 and toughness of 9.266.

6. Conclusions

At the end of the above research, the following conclusions can be drawn:

- The injection temperature; injection speed; and screw speed affect the UTS and toughness of the HDPE Reinforced with Flax Fibers Composites.
- Controlling process factors resulted in enhancement in the mechanical properties HDPE Reinforced with Flax Fibers Composites. Numerical optimization was found beneficial to achieve the optimum UTS and toughness.
- Most of the higher three factors interactions and some quadratic combinations of factors were found to have significant effect on the UTS and toughness and thus included in the model.
- Any attempt to reduce the model further and ignore higher order interaction results in the lack of fit being insignificant which means that these interactions can't be ignored and should be included in the model.
- Computer software can assist sometimes in computations taking into consideration that all attempts to reduce the model terms to enhance its simplicity failed drastically.

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