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A University of Dominican Republic Objective Empirical Teaching Evaluation Metric

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Abstract

A unique method is presented for evaluating university faculty contribution to student learning. The contribution is obtained by regressing inflation proof re-centered student cumulative grade point average (GPA) on the fraction of the total number of credit hours that students are taught by each professor. We postulate that the resulting regression coefficients measure the average rate at which each professor contributes to student learning as measured by cumulative grade points earned per contact hour of instruction. Since this model is based on grades that are assigned by individual professors, it is in effect a faculty peer evaluation of GPA outcome based learning as defined by the university. A privacy protected anonymous faculty and student body empirical study is conducted.

1. Introduction

The responsibilities of university faculty members include teaching, research and service. The purpose of this study is to construct an empirical instrument for evaluating the teaching component for the College of Engineering at Universidad Dominicana O&M. The model for teaching evaluation is based on the metric proposed by Ridley and Collins (2015). Since the three components of faculty responsibility are complementary functions (Sharobeam and Howard, 2002), the teaching evaluation metric (TEM) must be integrated into a full model that includes all three components, each weighted by its respective assignment of responsibility (Ridley and Collins, 2015).

The paper is organized as follows. A brief review of traditional student based teaching evaluation methods is given in the next section. This is followed by a review of the TEM model and an empirical case study, arriving at student survey evaluation and estimated TEM scores. Corresponding student evaluation scores and their utility are compared with the TEM scores. Then, the TES scores are presented and integration of the teaching evaluation metric into a full faculty evaluation metric is discussed. We end with summary conclusions.

2. Traditional Evaluation Methods

The validity of student evaluations has been studied extensively (e.g., Kozub, 2008; Ryan, Anderson and Birchler,1980; McNatt 2010; McPherson, Jewell and Kim, 2009). A negative relationship between student evaluations and student achievement was found by Yunker and Yunker (2003). It is possible for first impressions of instructors and grade expectations to influence student evaluation of teaching (Centra 2003; Buchert et al., 2008). A study by Marshall (2005) reported that student evaluations were ineffective and inefficient. They create evaluations that are highly skewed, requiring institutions to use percentile rankings of instructors (Clayson and Haley, 2011).

Administrator evaluation of teaching may be arbitrary, based entirely on the opinion of the administrator. The evaluations are not necessarily tied to teaching innovation, methodology, workload or currency of teaching material. They may not even be tied to learning (Coker, et. al. 1980, Weinstein, 1987). They may simply be based on the degree of correspondence of the teaching philosophies of the professor and those of the administrator. Whether justified or not, evaluations may be lowered if there are student complaints against the professor. Instead of studying hard, failing students may exercise political pressure against a professor, and administrators may make political choices between students and professor. Young professors tend to have high grading standards, a strong desire to build quality, intellectual curiosity, responsibility and study habits. They, more than others, are likely to be accused of failing students without good cause. They may be the victims of student evaluations known to be popularity contests, inversely related to learning (Coker, et. al. 1980, Weinstein, 1987).

Unreliable evaluations can cause instructors to perceive them as independent of what they do and how they teach. This can discourage high academic performance (Coker et. al. 1980; Weinstein, 1987). Student evaluations can also infringe on academic freedom (Haskell, 1997; Ryan et. al. 1980; Dershowitz, 1994; Stern and Flynn, 1995). A consensus has emerged that there is a need for a valid and reliable evaluation system of teaching (Wolfer and Johnson, 2003; Ma, 2005). A good evaluation system should promote academic rigor over getting by, critical thinking over memorization and regurgitation, understanding and intellectual leadership over deference, and meaningful grades. This may require a paradigm shift.

3. The Teaching Evaluation Metric

The instructional unit in this study is the Universidad Dominicana O&M, Dominican Republic, College of Engineering. The TEM is based on the following regression model:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_j x_{ij} + \ldots + \beta_k x_{ik} + \varepsilon_i; \qquad i = 1,2,3,\ldots,n; j = 1,2,3,\ldots k \qquad (1)$$

where

y_i = cumulative grade (re-centered around C=2 within each class) point average of the i^{th} student,

x_{ij}= fraction of total number of semester hours that the i^{th} student was taught by the j^{th} professor,

β_0= regression parameter representing the extent to which grade point average is unaffected by direct contact hours within the instructional unit,

β_j= regression parameter containing information regarding the impact that the j^{th} professor has on student grade point average, and the errors ε_i are independent and normally distributed with zero mean and constant variance σ^2,

k = number of professors in the instructional unit,

n = number of students.

The marginal rate at which the j^{th} professor contributes to student grade point average, ceteris paribus, is given by β_j grade points per contact hour of instruction. The measurement of learning is a difficult and contentious subject. The university places value on grades as an assessment of student competence to progress through various programs. Therefore, we need not justify grades as a measure of learning. All that matters is this assessment of competence. Assuming that grade points measure taught student competence then β_j represents the institution and instructional unit context specific teaching effectiveness of the j^{th} professor, in the presence of all contributions by all the other professors. Also, it is assumed that each professor contributes to student learning in some general way through advising or any number of other indirect ways, and that such learning is reflected in β_0. Therefore, teaching credit is determined from the teaching effectiveness coefficient $b_j = \beta_0 + \beta_j\ (estimated)$. It reflects the j^{th} professor's knowledge, proficiency, ability to impart knowledge, contribution to student intellectual development and study habit, ability to leverage the contributions to date made by all other professors, and contribution to the student's ability to perform in the professor's course, as well as, in other courses taken at the university. Of course, there is no way to ascertain the individual effect of each of these. We simply list them as attributes that may contribute to the average of grades. In order to correct for grade inflation and differences in grading standards, the grades reported for each class are re-centered around a grade of c=2 points before totalling up the grade points. For each class the re-centered grade values are the original grade values minus the average of the grade value for the class plus 2.0. Therefore, this is a professorial peer evaluation of the preparedness of each other's students. It is conducted by the best experts that the university has to offer. Furthermore, the evaluation is kept honest by grade re-centering (the average grade is the same for all professors). Grade re-centering must be explained to all faculty members to avoid any futile temptation to game the system by giving higher grades to their own students.

The teaching evaluation score (TES_j) for the j^{th} professor is based on a combination of the teaching effectiveness coefficient (β_j) and the teaching workload. It is measured by the total contribution to the number of student credit hours earned by students who were taught by the j^{th} professor, expressed as a fraction of the contribution to the grand total number of student credit hours made by all professors.

$$TES_j = (\textstyle\sum_{i=1}^{n} b_j H_{ij}) / \sum_{j=1}^{k} \sum_{i=1}^{n} b_j H_{ij}) = (b_j \sum_{i=1}^{n} H_{ij}) / (\sum_{j=1}^{k} b_j \sum_{i=1}^{n} H_{ij}) \qquad (2)$$

where H_{ij} represents the number of contact hours that the j^{th} professor taught the i^{th} student in the evaluation year. If the i^{th} student was not taught by the j^{th} professor during the evaluation year, then $H_{ij} = 0$. Since the intercept β_0 represents the extent to which grade point average is unaffected by direct contact hours within the instructional unit, its contribution to cumulative gpa must be distributed equally to all professors in the unit. That is, $b_j = \beta_0 + \beta_j\ (estimated)$. If the regression is run through the origin the estimated regression coefficients will change from $\beta_j\ (estimated)$ to $\beta_0 + \beta_j\ (estimated)$. Therefore, we choose to run the regression without an intercept. Either way, the value of TES_j is the same since TES_j is calculated from $b_j = \beta_0 + \beta_j\ (estimated)$.

If it were true that large class sizes lower teaching effectiveness, then the teaching effectiveness coefficient will be lowered. However, multiplying the teaching effectiveness coefficient by the number of student credit hours will increase the TES, and thereby offset the effect of class size on the TES. In order to assist in maximizing teaching effectiveness, the university should attempt to equalize and reduce class sizes. Where large class sizes are unavoidable, technology may be used to mitigate against reductions in teaching effectiveness.

4. Empirical Case Study

4.1. Student Data and Evaluation

Universidad Dominicana O&M is a private university in Santo Domingo, Dominican Republic, with a population of more than 45,000 students distributed in 7 campuses all over the country. It was established in 1966 and has several academic programs in humanities, engineering, technology, and medicine.

Currently, a survey applied to students at the end of the term (4 months), is used as a professorial evaluation method. The survey contains 22 ranking questions on a 5 point likert scale (1-5) and 3 binary questions (yes/no). Upon completion, the 22 ranking questions are averaged and an average rank is assigned to each professor. Figure 1 shows the Business Intelligence solution used to display the results.

Each professor is assigned a unique anonymous code. Like any Business Intelligence tool, it is very useful for drilling down to the evaluation for any professor, campus, course, etc. It provides a general overview of evaluations for individual professors as well as for groups of professors. Unfortunately, the information displayed is the opinion of students and not a score of the student learning outcome performance that is attributable to the professors.

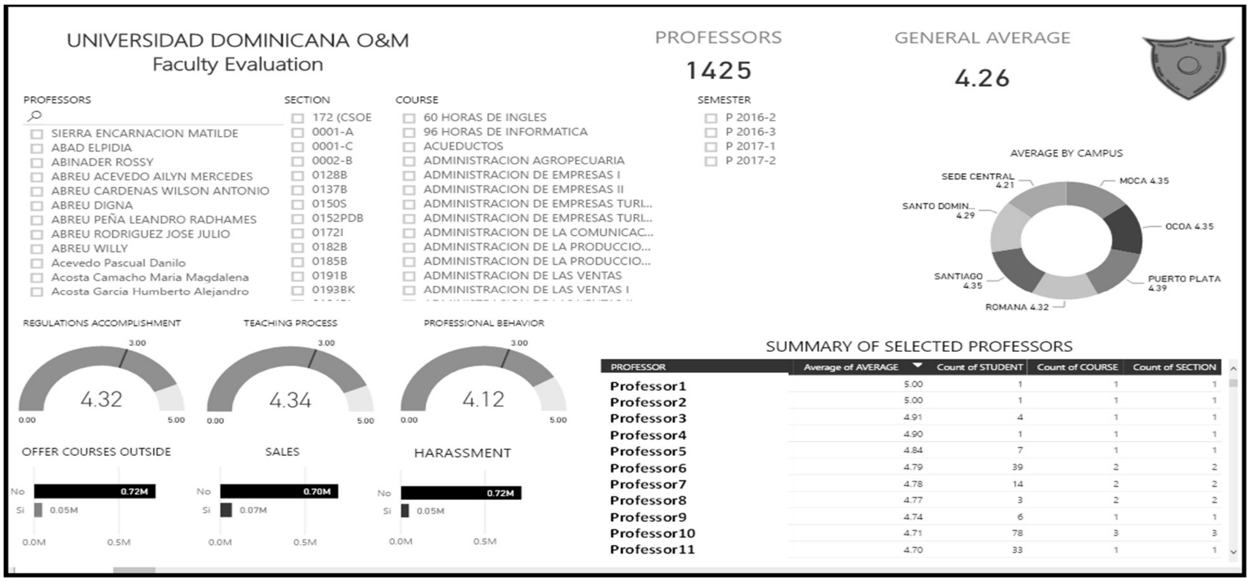

Figure 1. Student survey results and deployment

4.2. TES Data

The TES method was applied to the college of engineering students. Universidad Dominicana O&M has four engineering programs: Civil, Electronics, Industrial and Systems. The data used in this study correspond to the grades earned by students in the College of Engineering, including Civil, Electronics, Industrial and Systems. Figure 2 shows the distribution of grades (A, B, C, D, and F) for all students. A sample for three anonymous students is shown in Table 1. These letter grades have the corresponding numerical point values: A=4, B=3, C=2, D=1 and F=0. The numerical values enable the computation of a grade point average for each student. Figure 3 shows the proportion of each grade in the corresponding program. For the database used in this study, Civil Engineering presents the greatest proportion of F grades, compared with other programs. Industrial Engineering presents the greatest proportion of A grades. This is relevant information because it seems that TES is sensitive to the proportion of grades. In order to guard against the influence of grade inflation, the student grades are re-centered at 2 before estimating the regression models (Ridley and Collins, 2015). Re-centering in this way stipulates that the true average grade is C and the true average grade point is 2.

TABLE 1. Sample data for three anonymous students

Student ID	Course	Credits	Professor	Grade	Program	Semester
00-EIIN-1-152	ASEGURAMIENTO DE LA CALIDAD	4	ZOILA EVANGELINA JIMENEZ ESPINO	B	Industrial	P2017-1
00-EIIN-1-152	CONTABILIDAD DE COSTOS I	4	HECTOR TREJO ACEVEDO	B	Industrial	P2017-1
00-EIIN-1-152	HIGIENE Y SEGURIDAD	4	RAFAEL VICENTE	C	Industrial	P2017-1
00-EIIN-1-152	SISTEMA DE LOGISTICA	4	JOSEPH PE¥A	B	Industrial	P2017-1
00-EISN-1-257	ALGORITMOS COMPUTACIONALES	4	ANDRES PATI¥O	C	Systems	P2017-1
00-EISN-1-257	ARQUITECTURA DEL COMPUTADOR	3	DAVID UPIA	B	Systems	P2017-1
00-EISN-1-257	C++ Y PROGRAMACION ORIENTADA A OBJETOS	4	PATRICIA DAYANARA ARIAS BATISTA	A	Systems	P2017-1
00-EISN-1-257	DISE¥O Y ADMINISTRACION DE REDES	4	JOSE ENCARNACION	C	Systems	P2017-1
00-EISN-1-257	GERENCIA DE INFORMATICA	4	MARIS ENCARNACION ZABALA	C	Systems	P2017-1
00-EISN-1-315	C++ Y PROGRAMACION ORIENTADA A OBJETOS	4	STARLING GERMOSEN REYNOSO	A	Systems	P2017-1
00-EISN-1-315	DISE¥O Y ADMINISTRACION DE REDES	4	VICTOR ORTIZ	F	Systems	P2017-1
00-EISN-1-315	GERENCIA DE INFORMATICA	4	RICARDO GARCIA V.	B	Systems	P2017-1
00-EISN-1-315	HERRAMIENTAS DE MULTIMEDIA	4	ALFONSO DE LOS SANTOS	C	Systems	P2017-1

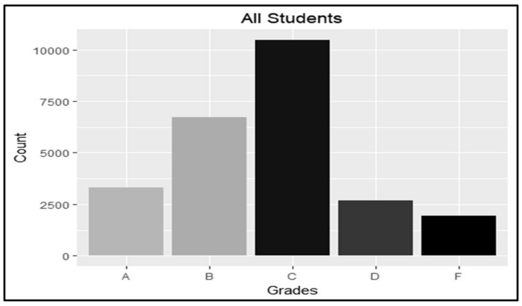

Figure 2. Grade distribution for all students.

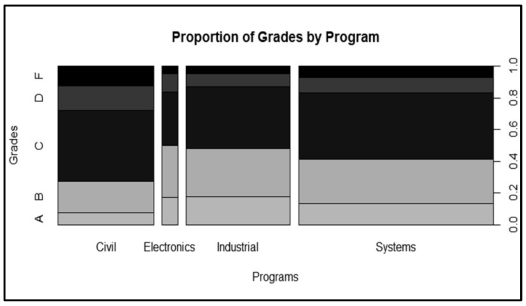

Figure 3. Grade distribution by Program

Each program has a different number of professors, students and courses. For the study period Table 2 shows the distribution within the data base.

Table 2. Data set

Program	Professors	Students	courses
Civil	65	1,748	62
Electronics	29	342	38
Industrial	88	1,915	56
Systems	167	3,296	65
TOTAL	**349**	**7,301**	**221**

4.3. TES Results

The TES model was applied to the preceding data set. Figure 4 shows the relationship between TES and the weekly class contact hours taught by professors. As expected the higher the number of credit hours taught by professors weekly, the higher is the TES. But, there are special cases that can be seen from the chart. The trend line separates professors that are above and below the average TES at any given number of hours of instruction.

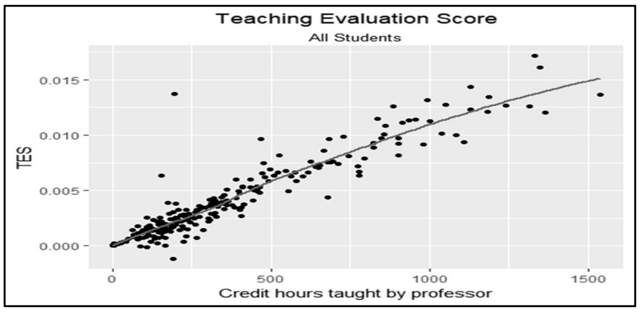

Figure 4. TES vs Hours of Instruction

Because TES is a relative score, if it is computed separately for professors within their respective programs the relative scores remain the same, but the absolute values of the scores change. See Figure 5. Notice that in Figure 4, there is a professor with an unusually high TES of about 0.013 to 0.014. The corresponding hours taught is about 200 hours. In Figure 5 we see that the unusually high TES occurs in the Systems Engineering program with a corresponding hours taught of about 200 hours. The relative location of the data point is the same. But, since the data sample is different, the actual TES is different (about 0.03).

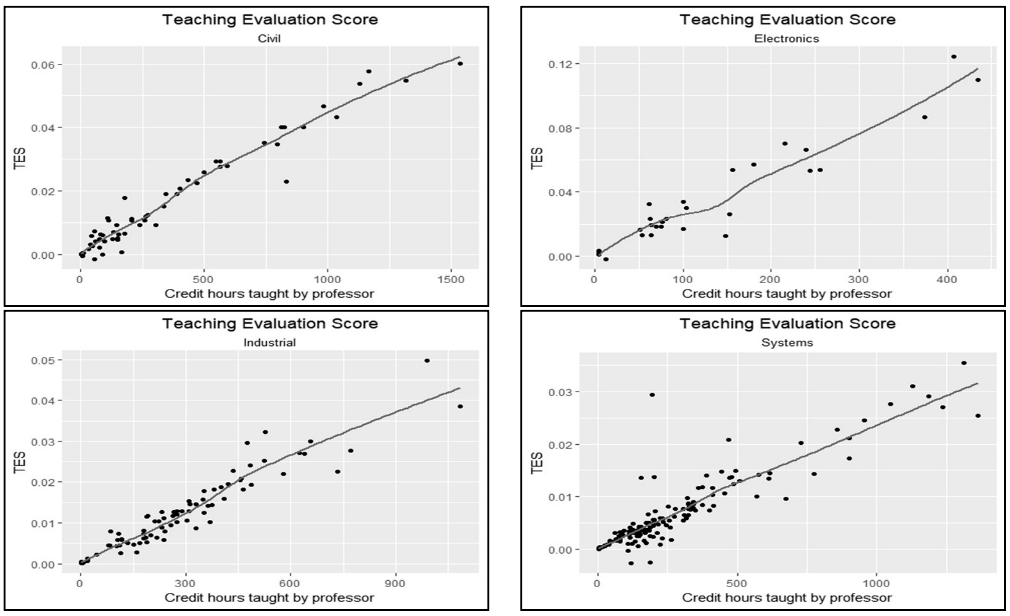

Figure 5. Teaching Evaluation Score by Program

The goodness of fit of the regression models are shown in Table 3. The five regressions have very good R^2 and adjusted R^2 coefficients. The errors are normally distributed and there are no patterns in the plot of residuals vs fitted values, so there are no concerns regarding the systematic assignment of high or low GPA students to any professor.

Table 3. R^2 of Regression models

Model	R^2	R^2 adj
All Students	0.89	0.89
Electronics	0.91	0.90
Civil	0.88	0.87
Industrial	0.92	0.91
Systems	0.90	0.90

A sample of the five highest and five lowest systems engineering TES scores is given in Table 4. Each professor's TES score is determined by the credit hours taught by the professor and by the professor's contribution to gpa performance of the individual students who they teach. A high number of credit hours does not guarantee a high TES. For that, a high teaching contribution is also required. The TES scores are expressed as a percentage contribution to the grand total number of student credit hours earned. Once again, the name of each professor is replaced with a unique anonymous code.

Table 4. Highest and lowest TEM scores for a sample of ten systems engineering professors

PROFESSOR	b_j	CREDIT HOURS $\sum_{i=1}^{n} H_{ij}$	$b_j \sum_{i=1}^{n} H_{ij}$	$TES_j\%$
Professor1	2.19	1,312	2,873.28	3.55
Professor2	2.23	1,130	2,519.90	3.11
Professor3	12.15	196	2,381.40	2.94
Professor4	1.99	1,188	2,364.12	2.91
Professor5	2.14	1,051	2,249.14	2.77
….	…	…	…	…
Professor163	1.75	3	5.25	0.01
Professor164	-0.24	6	-1.44	-0.00
Professor165	-0.29	110	-31.90	-0.04
Professor166	-1.10	190	-209.00	-0.26
Professor167	-1.89	120	-226.80	-0.28
			$\sum_{j=1}^{k} b_j \sum_{i=1}^{n} H_{ij}$=81,000.00	$\sum_{j=1}^{k} TES_j$=100.00

4.4. Discussion

The first consideration with respect to the adoption of the TES is a comparison of the student evaluation model and the TES model evaluation. When the student evaluation is plotted against credit hours taught by professor (see Figure 6), there is no discernible pattern to suggest that the two variables are correlated. The student evaluation scores are heteroscedastic. When student evaluation is plotted against TES (see Figure 7), there is no discernible pattern to suggest a relationship. The correlation is r=-0.053 and $R^2 = (-0.053)^2 = 0.002809$ which is negligible. Student evaluations are not a predictor of professor contribution to student assessment of competence as measured by gpa. The TES is potentially a better predictor of professor contribution to student assessment of competence. Therefore, we choose the TES score."

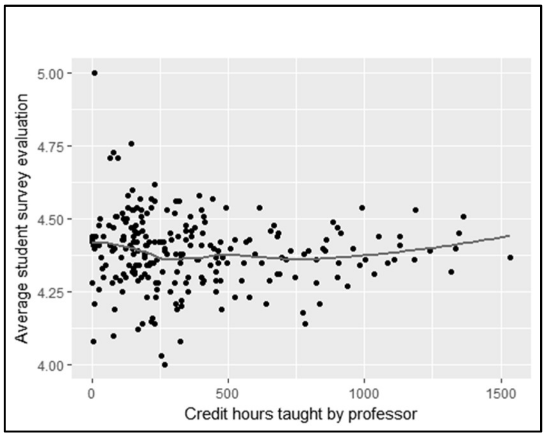

Figure 6. Student survey evaluation vs Credit hours taught

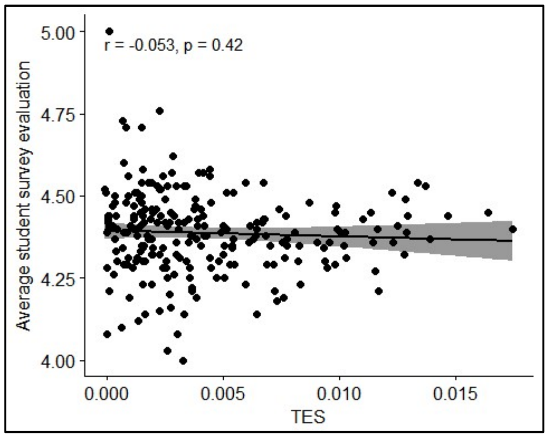

Figure 7. Student survey evaluation vs TES

4.5. Integration Into The Faculty Evaluation Metric

The TEM may be integrated into an objective professorial evaluation metric (PEM) that is used to determine a professorial evaluation score (PES). The PEM is designed to incorporate measures of teaching, research and service. It includes the TEM, used to determine a teaching evaluation score (TES); a research evaluation metric (REM), used to determine a research evaluation score (RES); and a service evaluation metric (SEM), used to determine a service evaluation score (SES). The PES is an overall measure of a professor's contribution, expressed as a fraction of the total contribution of all professors in the instructional unit. The PEM accounts for uneven distribution of effort and prior assignment of responsibility between teaching, research and service, between professors, and between different time periods. It is used for annual evaluations, merit reward, tenure and promotion. Professorial contributions require time to take effect. The PEM is defined in the appendix.

5. Conclusions

The teaching evaluation component of the professional evaluation metric was calculated for the College of Engineering at Universidad Dominicana O&M. The TES regression method teaching evaluation scores were compared to the student evaluation method and scores for the same population of professors. The student evaluation scores bore no discernible correlation that would suggest it is a reliable predictor of student grade point average. The high coefficient of multiple determination between TES and the number of credit hours taught suggests that it is a reliable predictor of student grade point average. The TES scores versus credit hours taught trend upward to reflect the additional hours taught by some professors per their assignment of responsible. Other professors may have relatively higher assignment of responsibility for research. The TES can only be applied if full consideration is given to the assignment of responsible. Much depends on the professor's activities that he or she is responsible for. The faculty job description can depend on the mission of the university. Typically the job description includes teaching, research and service with various weights that reflect the mission of the university. This paper is only concerned with the teaching activity. The appendix in this paper provides complete instructions for integrating the TES component into the full professorial evaluation metric.

6. APPENDIX

For the purpose of giving the most general possible description of the PEM model, assume that the number of professors in an instructional unit is k. Then let the professor code be *j* where *j*=1, 2, 3, ... *k*. The professorial evaluation score for the j^{th} professor is determined as follows:

$$PES_j = T_j TES_j + R_j RES_j + S_j SES_j \tag{A.1}$$

where
TES_j = Fraction of total professorial teaching contribution made by the j^{th} professor,
RES_j = Fraction of total research contribution made by the j^{th} professor,
SES_j = Fraction of total service contribution made by the j^{th} professor,
T_j = Fraction of the j^{th} professor's assignment of responsibility given to teaching (≥0.25 i.e., average at least one 3hr. course per semester to maximize the TES contribution to the PES).
R_j = Fraction of the j^{th} professor's assignment of responsibility given to research (≥0.20),
S_j = Fraction of the j^{th} professor's assignment of responsibility given to service (≥0.05≤0.1),
$T_j + R_j + S_j = 1$ (assigned prior to the evaluation period then revised later to maximize PES),
j = 1,2,3... *k*, and *k*= number of professors in the instructional unit.

A 5 year total PES will measure long, continuous and productive contributions. These and additional details of the models for determining TES, RES and SES are given in Ridley and Collins (2015).

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Optimization of Nurse Staffing under Varying Preferences

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Abstract

Staff scheduling in hospital emergency departments is challenging due to the uncertainty involved in the work needed to be performed, the high impact if the work is not performed, and the non-traditional working hours. Also, the desires of the stakeholder on what should be optimized may not be clear. This paper addresses the impacts of preferences in the staffing of emergency department nurses. The research uses data collected from a local hospital on patient flow to model nurse staffing. This model is used in an optimization framework where objective functions and constraints are varied to determine their impact on scheduling. Value models of patient care and wasted funds, as well as four constraints are explored in this research. The research concludes that understanding and representing the stakeholder's preference properly is critical in determining an optimal schedule.

1. Introduction

Hospital administrations have the difficult task of scheduling workers where uncertainty in the work that needs to be performed exists (Bruin, Rossum, Visser, & Koole, 2007). High impact exists on both patients and the hospital if the work is not performed to a certain set of standards (Van Den Bos et al., 2011), and non-traditional working hours exist (Trinkoff, Le, Geiger-Brown, Lipscomb, & Lang, 2006). In addition, the preferences of the stakeholder must be well understood if a preferred schedule is to be formed. Examples of preferences that are relevant to the health care sector are minimizing costs, maximizing profit, maximizing patient satisfaction, and minimizing employee attrition. These preferences indicate desire for one alternative over another alternative.

To determine a preferred schedule, two things are needed: a preference and a prediction of a future state. This paper leverages patient flow data on Emergency Department (ED) nurse staffing for a local hospital in Northern Alabama to establish a demand prediction model. There are two preferences specified by the local hospital that are examined in this paper. The first preference is to ensure that there are enough nurses scheduled to meet hospital needs. The second preference is to ensure that resources are not being wasted by scheduling nurses who are not needed. While there are many ways to approach these preferences, this paper opts for an optimization and value model approach. Therefore, the goal of this paper is to demonstrate optimization in nurse staffing by using value models (Collopy & Hollingsworth, 2011) to represent preferences and to explore how the preferences impact the optimal schedule. The importance of properly representing preferences will be demonstrated in this study.

2. Background

2.1. Scheduling and staffing

Scheduling is a collection of processes, models, and algorithms (Brucker & Knust, 2012; Kerzner, 2001) where the models are classified as either deterministic or stochastic (Pinedo, 2012). The practices of scheduling workers for an organization is generally referred to as staffing. Previous research has outlined good practices for staffing (Schneider, 1976), including the development of five principles that have proven effective for organizational performance (Terpstra & Rozell, 1993). These principles should be considered in the hiring process and generally before optimizing a work schedule.

Demand modeling needs to be considered first when optimizing staffing procedures (Ernst, Jiang, Krishnamoorthy, & Sier, 2004). The types of staff needed must also be determined. Types of staff include full-time employees and non-standard work relations that include part-time, temporary, and flexible staff (Houseman, 2001; Kalleberg, 2000). Flexible staff types are prevalent with nurses in EDs.

2.2. Nurse and emergency department staffing

Previous research focuses on specific concerns involved in the nurse staffing decisions including patient acuity, overcrowding, tradeoffs with quality of care, and department efficiency. Previous work has simulated staffing based on patient acuity levels, also referred to as triage (Connelly & Bair, 2004), providing an effective method to simulate mean treatment times for emergency department patients (Connelly & Bair, 2004). Other work has proposed a method to construct balanced workload assignments for nurses while accounting for patient acuity and distances that nurses have to travel (Acar & Butt, 2016). Previous research has addressed overcrowding by a queuing model to determine when to provide and how to allocate physician staffing for an ED (Green, Soares, Giglio, & Green, 2006). This model was able to decrease the number of patients turned away (Green et al., 2006). An alternative way to decrease overcrowding is by scheduling more nurses or by increasing their number of work-hours; this has been shown to reduce patient throughput time, which in turn, reduces crowding (Needleman, Buerhaus, Mattke, Stewart, & Zelevinsky, 2002).

Other research has examined ED efficiency with simulations incorporating ED physician work schedules to evaluate changes in patient throughput (Rossetti, Trzcinski, & Syverud, 1999). By using this model, a schedule was developed that reduced patient throughput time by 14.5 minutes per patient (Rossetti et al., 1999). Increasing the number of nurses generally increases quality of care (Needleman et al., 2002) (Kane, Shamliyan, Mueller, Duval, & Wilt, 2007) (Blegen, Goode, & Reed, 1998), but there are also costs that must be balanced (Lankshear AJ, Sheldon TA, & Maynard A, 2005). Because of this balance, hospitals began to use mandatory nurse to patient ratios to staff hospital departments (Tevington, 2011). Previous research has examined the negative effects of each additional patient per nurse on nurse burnout, job dissatisfaction, and patient mortality (Aiken, Clarke, Sloane, Sochalski, & Silber, 2002). While the past research has resulted in significant improvements for specific performance metrics, the preferences represented by objective functions that are optimized in the past research has varied greatly.

2.3. The Relationship Between Preferences and Previous Research on Nurse Schedule Optimization

The nurse staffing problem is known as the “The Nurse Scheduling Problem” or “The Nurse Rostering Problem” and is NP-hard in complexity (Rajeswari, Amudhavel, Pothula, & Dhavachelvan, 2017). Previous research has primarily focused on specific objective functions, with a focus on the performance metrics of the study. The preferences previously explored are shown in Table 1. The research presented in this paper focuses on the preferences that shape the optimization problem.

Past research has commonly used "hard" and "soft" constraints to solve the nurse rostering problem (Aickelin & Dowsland, 2004; Berrada, Ferland, & Michelon, 1996; Burke, Li, & Qu, 2012; Dowsland, 1998; Gutjahr & Rauner, 2007; Rajeswari et al., 2017; Wu, Yeh, & Lee, 2015). "Hard" constraints tend to be contract specifications, like work hours in a week, and "soft" constraints are representations of nurses' desires, such as working only a certain number of days in a row (Aickelin & Dowsland, 2004; Berrada et al., 1996; Burke et al., 2012; Dowsland, 1998; Rajeswari et al., 2017; Wu et al., 2015). A modification to the typical use of "soft" constraints is to incorporate the desires of the hospital as "soft" constraints, such as desiring a certain number of more experienced nurses on a shift (Gutjahr & Rauner, 2007). Many of the objective functions implement a cost/penalty that is associated with not satisfying a "soft" constraint (Aickelin & Dowsland, 2004; Dowsland, 1998; Gutjahr & Rauner, 2007; Rajeswari et al., 2017). Others maximize the completion of "soft" constraints (Berrada et al., 1996; Burke et al., 2012). One model differed by using the average nurse work pattern and minimized the deviations from it to maximize the fairness of the schedules (Wu et al., 2015). The research presented in this paper focuses on the preferences that shape the optimization problem and how the resulting schedules differ.

Table 1. Preferences used in literature

Reference	Objective Functions Used
(Rajeswari et al., 2017)	Minimize Penalty cost from soft constraint violations.
(Dowsland, 1998)	Minimize Penalty cost from soft constraint violations.
(Berrada et al., 1996)	Maximize satisfaction of soft constraints
(Burke et al., 2012)	Minimize hard constraint violations/ maximize soft objectives
(Wu et al., 2015)	Maximize fairness of nurse schedules
(Gutjahr & Rauner, 2007)	Penalty/Cost Minimization for variable-weighted constraints
(Aickelin & Dowsland, 2004)	Minimize cost function

2.4. Preference Representation

Mathematical representation of hospital stakeholder preferences will be performed in this paper using value models (Collopy & Hollingsworth, 2011). Value models are essentially special case objective functions where the units are meaningful and a single desire is maximized or minimized. Value models have been used in a variety of applications in order to rank order alternatives, including electric vehicles (Topcu & Mesmer, 2017), fractionated satellites (Brown, Eremenko, & Collopy, n.d.), and evacuation modeling (Mesmer & Bloebaum, 2014, 2015, 2016).

3. Methodology

3.1. Problem and Data

The hospital's ED's current approach to scheduling nurses is based on a utilization metric. Utilization is defined by the hospital as the number of nurses divided by the number of patients, seen in Equation 1. One nurse for every two patients (U=0.5) is the "ideal ratio" as described by the hospital. The ED's current method to schedule nurses is based on trying to average 100% utilization throughout the day. As of September of 2014, the allotted utilization was running at approximately 107%. This indicates that there is an excess of nurses compared to patients, so a hiring freeze was implemented and shifts were cut. This has led to nurse to patient ratios below acceptable levels at certain times of the day.

$$U = \frac{N}{P} \tag{1}$$

$where:$
$U - Utilization\ (\%)$
$N - Number\ of\ nurses\ working$
$P - Number\ of\ patients$

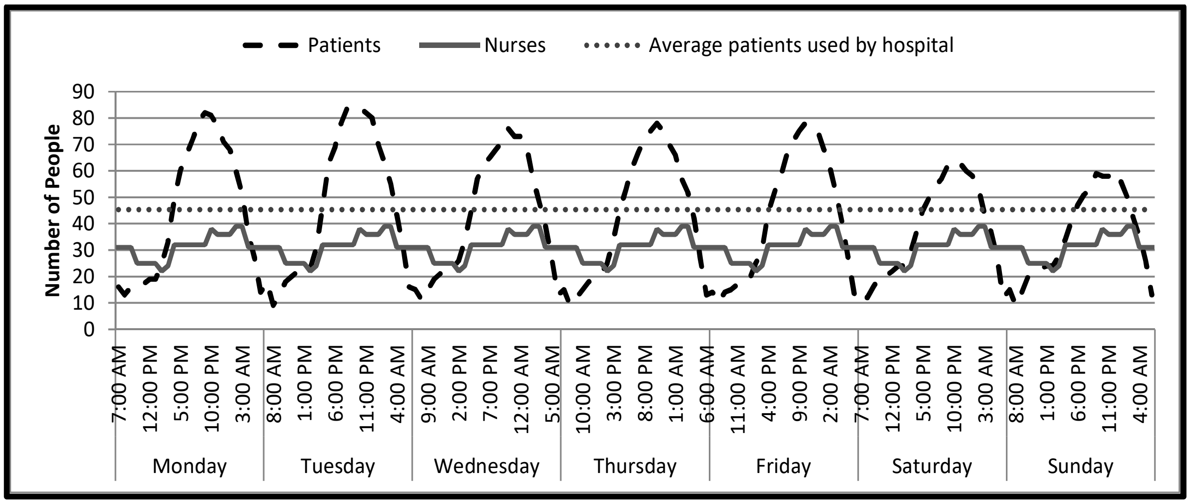

Figure 1. Data collected from local hospital

Figure 1 displays the data used by the hospital for their current scheduling process. The dashed line is the average number of patients for the day and time specified. The dotted line is the number of patients used by the hospital in determining their scheduling, found by averaging the patient flow. The number of nurses is shown by the solid line. The hospital's current model for scheduling takes the average number of patients that were checked in at any given time and assigned a consistent, daily schedule for the nursing staff. The most notable issue is that the nurse count is higher than the nurse demand during the times of lower patient traffic. This issue arises because the current schedule does not take into account variation in patient traffic throughout the day or week. The patient data shows a common daily trend, with a decrease in magnitude from Monday to Sunday. For the new model, a single day (Monday) is examined due to its high variation of patients throughout the day. Monday is defined as 7am Monday to 7am Tuesday. With data established to predict the future states of patient flow, the next step is to establish preferences and represent them mathematically.

3.2. Preferences

Two preferences are explored in this paper. These preferences are assumed to capture desires of the hospital stakeholders concerning staffing. To enable the use of optimization, these preferences are represented mathematically by value models, used in the optimization as objective functions. Both value models are formed to result in the minimum being the most preferred outcome.

The first preference examined in this paper is to maximize patient care. Patient care is related to the patient to nurse ratio. The lower this ratio, the higher is the patient care. This preference is represented mathematically in the value model of Equation 2, defined as the average patient to nurse ratio. The time increments for the calculation are hourly, from 7am Monday to 7am Tuesday. This equation will be minimized in order to result in the preferred outcome.

$$V_{pc} = \frac{\sum_{t=1}^{T} \frac{P_t}{N_t}}{T} \tag{2}$$

$Where$:

t-time increment

T-total number of time increments

The second preference examined is to conserve funds. Funds can be conserved in scheduling by reducing the money spent on employees, effectively reducing the number of nurses working. To develop a reasonable representation of the conserve funds preference, the value model of the average of an error was formed, shown in Equation 3. The error is determined from an "ideal" value of 2 based on discussions with hospital stakeholders and a factor of safety of .5.

$$V_f = \frac{\sum_{t=1}^{T} \left|1.5 - \frac{P_t}{N_t}\right|}{T} \tag{3}$$

3.3. Constraints

The two value models outlined above are simple abstractions of the stakeholder preference. Because they are simple, and incomplete, optimizing them may lead to unusable solutions. For example, minimizing equation 2 will lead to an infinite number of nurses. To properly constrain the design space for this problem, necessary due to the simple value models, four sets of constraints were examined. These constraints will be combined with the value models to form eight different optimization problems to be examined.

The first constraint limits the average utilization to be less than 100%. This constraint aligns with the hospital's "budget" given to the ED of 100% utilization. The constraint is seen in equation 4.

$$g_1 = \frac{\sum_{t=1}^{T} \frac{N_t}{P_t}}{T} - 1 \leq 0 \tag{4}$$

The second set of constraints limit the shift start times to between 7am and 7pm. This set of constraints will be tied to a model modification where the shifts are always 12 hours in length. The set of constraints is shown in equation 5. Note that 7am is the zero hour for the model.

$$0 \leq S_i \leq 12 \quad i = 1..4 \tag{5}$$

$Where$:

$S -\ Shift\ Start\ Time$

$i - Shift$

The third set of constraints ensures that the end time of the shifts is after the start time of the shifts, shown in equation 6. When these constraints are added, the 12-hour shift length constraint is removed. Since the shifts don't have to be 12 hours long, this constraint is needed to enforce that there are no shifts with negative hours. For this to work, each shift has to start and end within 7am Monday and 7am Tuesday.

$$g_{1+i} = S_i - E_i \leq 0 \tag{6}$$

$Where$:

$E - Shift\ End\ Time$

The fourth set of constraints ensures that no shift goes beyond 12 hours in length if the start time and end time are variable. This is shown in equation 7.

$$g_{5+i} = E_i - S_i - 12 \leq 0 \tag{7}$$

3.4. Design Variables

Variables must be defined in order to explore the design spaces defined by the value models and constraints. Design variables are variables that can be changed by the designer that impact the system. In this case, the system is the nurse schedule. Three sets of design variables are combined with the four constraint sets and the two value models described below.

The first set of design variables is the number of nurses on each of four shifts. The design variable set is shown in equation 8 with the relationship to the number of nurses working shown in equation 9.

$$X = [n_i] \tag{8}$$

$Where:$
$n - number\ of\ nurses\ working\ on\ shift\ i$

$$N_t = \sum_{i=1}^{4} \begin{cases} if\ S_i \le H_t < E_i & n_i \\ else & 0 \end{cases} \tag{9}$$

$Where:$
$H - time\ of\ increment\ t\ adjusted\ to\ zero\ hour = 7am$

The second set of design variables is the start time of the shifts (S_i). The third set of design variables is the end time of the shifts (E_i).

3.5. Optimization Problem Statement

Table 2: Optimization Problems

Prob.	Value Model	Prob.	Value Model	Design Variables	Constraints	Side Constraints
1	V_{pc}	5	V_f	$[n_i]$	g_1	
2	V_{pc}	6	V_f	$[n_i; S_i]$	g_1	$0 \le S_i \le 12$
3	V_{pc}	7	V_f	$[n_i; S_i; E_i]$	$g_1;\ g_{1+i}$	$0 \le S_i \le 24$; $0 \le E_i \le 24$
4	V_{pc}	8	V_f	$[n_i; S_i; E_i]$	$g_1;\ g_{1+i};\ g_{5+i}$	$0 \le S_i \le 24$; $0 \le E_i \le 24$

Using the value models, constraints, and design variables described above, eight different optimization problems were formed. Table 2 summarizes the problems. Optimization problems 1 and 5, 2 and 6, 3 and 7, and 4 and 8 only differ in their value models. Problems 1 and 5 assume that the schedule designer can vary the number of nurses on set 12 hours shifts starting at 7am, 9am, 3pm, and 7pm. Problems 2 and 6 allow the designer to change the number of nurses per shift and the shift start times, assuming 12 hour shifts. Problems 3 and 7 allow the designer to change the number of nurses per shift and the shift start and end times, assuming no limit on shift length. Problems 4 and 8 allow the designer to change the number of nurses per shift and the shift start and end times, limiting the shift lengths to 12 hours. A common constraint for all of the problems is that the average utilization is at or below 100%.

The model is formed in Microsoft Excel. Inputs to the model include the number of nurses working for each of the four shifts and the start and end times of the shifts. Output variables include the average, minimum, and maximum utilization and patient to nurse ratio, and a graph that displays the number of nurses and the number of patients (from the collected data for a Monday).

With the model formed in Microsoft Excel, the optimization was performed using the Solver add-in. Due to the non-linearity of the design space an evolutionary algorithm was chosen. The optimization was run until a convergence of .0001 was achieved or the algorithm timed out. If the algorithm timed out the optimization was performed again in an attempt to obtain the global minimum.

4. Results and Discussion

A summary of the results of the study are shown in Table 3. It can be seen that each of the preference statements (which includes the value model and constraints) results in a different outcome, with the exception of problems 2 and 4. These differences are seen even though the preference statements explored in this paper were not drastically different. This highlights how important eliciting the correct preference from the stakeholder is when determining the best schedule.

The patient care preference problems (1-4) were all optimal when the utilization constraint (g_1) was active. This indicates that the optimizer was driving to have the most nurses possible, limited by the hospital's "budget". As the design space becomes more open (i.e. reducing the restrictions on the shifts), it is seen that the range between the minimum and maximum patient to nurse ratios at the optimum decreases, indicating less variation in the ratios. The patient care preference data also indicated that more shifts may be better, as the optimal shift durations were not zero indicating that all of the shifts were deemed useful. This is logical, as more shifts would allow for a better tracking of the number of nurses with the number of patients.

The conserve funds preference problems (5-8) were never restricted by the utilization constraint (g_1). This is logical as the objective function is pulling the incremental patient to nurse ratios to 1.5. It is noted that the averages of the patient to nurse ratios for the problems are not exactly 1.5 because of the 4 shifts. If more shifts were possible then the desired ratio could be met at each time increment. Similar outcomes to the patient care problems were seen relating to design space openness and ratio variations, as well as shift durations not driving to zero.

Overall many similar trends were seen between the patient care and conserve funds preference problem sets. One key similarity was seen when full freedom of shift start and end times was given to the optimizer. Three of the resulting shifts, for each of problem 3 and 7, were longer than 12 hours. The first shift was held to less hours in order to get the department through the quick increase in patients in the morning. While the shift durations were generally longer, the total number of nurses working in a day were the lowest for the specific preferences in this scenario. Due to the longer hours, the person-hours worked for problems 3 and 7 were unremarkable from the related problems. The results indicate that the preferences used in the study need further elaboration to drive to more reasonable solutions while still enabling an open design space.

Table 3: Optimal Number of Nurses per Shift

	Optimization Problem							
	1	2	3	4	5	6	7	8
Shift 1 Nurses; Length	34; 12	37; 12	33; 9	37; 12	26; 12	26; 12	18; 5	26; 9
Shift 2 Nurses; Length	34; 12	34; 12	29; 15	34; 12	18; 12	16; 12	11; 13	34; 10
Shift 3 Nurses; Length	27; 12	25; 12	22; 17	25; 12	17; 12	18; 12	21; 16	24; 10
Shift 4 Nurses; Length	29; 12	29; 12	26; 15	29; 12	22; 12	30; 12	26; 19	24; 11
Total Nurses	124	125	110	125	83	90	76	108
Person-Hours	1488	1500	1496	1500	996	1080	1063	1078
Average P/N	1.039	1.036	1.020	1.036	1.52	1.40	1.43	1.42
Min P/N	0.8	0.8	0.9	0.8	1	0.7	0.9	0.9
Max P/N	1.4	1.4	1.3	1.4	2.2	2	1.8	2
Average Utilization	100%	100%	100%	100%	69%	75%	73%	73%
Min Utilization	73%	74%	81%	74%	47%	51%	57%	52%
Max Utilization	138%	138%	124%	138%	105%	143%	124%	114%

5. Conclusion and Future Work

In conclusion, it was found that it is critical to correctly understand and mathematically represent preferences of hospital stakeholders when performing schedule optimization. This is in fact true for any system, as an optimization is only as good as the models and preferences that are used. The study, using actual patient flow data at a local hospital, indicated that improvements to the current schedule could be made. The study also indicated that a reexamination of the number of shifts and their lengths could lead \to more preferred solutions. Future work will focus on developing more sophisticated value models to represent the preferences of the stakeholders. These value models will capture more nuanced desires of the stakeholders, such as maximizing profit of the hospital. To supply the value models with the necessary attributes, a more detailed system model will also need to be formed. Multiple means of capturing these preferences will be used, including questionnaires, interviews, and document analysis.

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Social Media Impact on Attention Span

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Abstract

The present study consisted of 209 respondents participating in a self-administered questionnaire developed by the researchers. The study purpose was to test three hypotheses. The first hypothesis was the number of social media accounts has no relevance to the length of attention spans. The second hypothesis was there is no difference in attention span length amongst frequent use of episodic social media and frequent use of non-episodic social media accounts. The third hypothesis was there is no difference in attention span length amongst users preferring mobile versions of social media versus computer versions. The study findings accepted three hypotheses. Future research is also addressed in the conclusion.

1. Introduction

The number of users and unique visits daily to social media sites are increasing exponentially (Keenan & Ali, 2009). Different social media sites encourage sociability in unique ways based on features or design practices of these sites that enable users to socialize with each other. Social media is a component of individuals' lives that continues to affect how humans socialize. The present study identified if participants with shorter attention spans have more social media accounts, prefer episodic social media applications and have a high frequency of use of their social media accounts from a mobile device or computer. Lukinova, Myagkov, and Shishkin (2014) discuss how evolutionary psychologists suggest that humans are social animals that crave a social environment. It is not surprising that online social networks emerged to feed humans desire to be part of a social environment. For individuals that cannot socialize in person such as those that live at a distance from their family and friends or that have a medical condition, social media networks can fulfill humans' need to be social.

The researchers developed the terms episodic and non-episodic social media as a method to classify different types of social media. A definition for episodic social media is social media that occurs at irregular intervals consisting of loosely connected information. Instagram, Snapchat, Twitter and Vine fall under this definition since each tweet, video or picture is often a stand-alone piece of information that does not have to be in relation to previous or future pieces of information. Episodic social media also has limitations on the number of characters and/or a limited time that a post appears. For instance, Twitter is limited to the number of characters allowed in a post and posts from strangers appear in a Twitter feed. Snapchat and Vine have pictures or videos that appear only for a brief time. Non-Episodic social media networks refers to Facebook, Google+, LinkedIn, Pinterest, Tumblr and YouTube. The researchers define non-episodic social media as social media with a blog-type interface scheduled for a fixed interval of time such as a scheduled Hangout in Google+. Facebook, Tumblr, and Pinterest all have a blog-type feel that tells more stories than the short bursts of information of Snapchat, Vine, Twitter, and Instagram.

The study was comprised of 209 respondents that participated in a self-administered questionnaire developed by the researchers and conducted at a private university in the southeast. The literature review discusses social media and online sociability. The three hypotheses tested were on the relationships of social media technologies with respect to attention span. More details are in the research hypothesis, methodology and results sections. There is a discussion on the future research in the conclusion.

The hypotheses tested were on the relationships of social media technologies with respect to attention span. Attention spans refer to the amount of time an individual is able to focus before becoming distracted or easily bored (Oliver, 2000). Today, individuals are constantly on an information overload from both the quantity of information available and the speed of which information gets into the hands of individuals through advertising and multimedia. Attention deficits tend to be increasing as it is challenging to attract individuals and hold their attention long enough for people to read or watch messages such as work memos, advertisements, etc.

H1: The number of social media accounts has no relevance to the length of attention spans.
H2: There is no difference in attention span length amongst frequent use of episodic social media and frequent use of non-episodic social media accounts.
H3: There is no difference in attention span length amongst users preferring mobile versions of social media versus computer versions.

2. Literature Review

2.1. Social Media

Social media networks provide users with the ability to share public musings, private messages, photos, songs and videos as a means to express themselves (Keenan et al., 2009; Alexa, 2015). The internet's most visited sites are social media websites (Alexa, 2015). Social media has a specific structure for interactions inscribed into social networking sites (Bakardjieva & Gaden, 2012). The technological platforms that structure and control the social media exchanges have changed over the years from various broadcast media formats to groupware designs. Spies, Shapiro and Margolin (2014) suggests that adolescents and young adults initially dominated social networks that lead to parents' eventual entrance into the social network phenomenon. Approximately 73% of adolescents are users of social networking sites despite the terms of service for some sites restricting use to those age 13 or older (Lenhart, 2009; Lenhart, 2012; Lenhart et al., 2016). More alarming is the amount of time spent by adolescents and young adults using electronic media with the number of hours daily being as high as over 11-hours for 11-18 year olds (Kaiser Family Foundation, 2016). Users that are older such as late adolescents and emerging adults average approximately 30-minutes daily for just Facebook that does not calculate the time spent on all social media networks (Pempek et al. 2009).

Duarte and Snyder (1999) identified different modes of communication as audio, video or data. Rudall and Mann (2007) discuss how computing has shifted into combining both social and technological aspects. Some of the most used forms of technology are RSS feeds, photo and video sharing services, blogs, forums, social tagging, social networking and wikis (Chua et al., 2012). Blogs tell a story allowing anyone to voice their opinions. Wikis allow public collaboration and input. RSS feeds provide automated notifications of regularly updated content of interest. Becker and Carstens (2011) identified technology categories as collaborative project, blogs and microblogs, content communities and social networks. Collaborative projects include wikis such as Wikipedia that allows users to add, remove, and change text-based content. Another example is rating of Internet links of media content such as Reddit. Blogs and microblogs generate content shared with others that date-stamp entries. Microblogs differ from blogs in that their content is limited such as limited characters allowed for Twitter users. Content communities such as YouTube offer the capability of sharing media among users added to their profile or for the public to view. Social networks have more extensive personal profiles where sharing of information and media among friends take place. Governments also use blogs, wikis, social networking, media sharing, microblogging and mashups (2010).

Park et al. (2012) surveyed 280 college students with research findings suggesting that frequency and preference of text-based communication technology use is dependent on multiple factors including social influence, media richness, and individual motivation. The study included examining different roles that these factors play in technology use of e-mail, cell-phone texting, and Facebook wall postings. Social circumstances were measured by asking the respondents to identify which platforms are most used by people they communicate with regularly and by the people whose opinions they value. Media richness was also measured through respondents' perspective that the platform provides timely feedback and delivers a variety of different cues beyond written messages. Individual motivation was measured by the respondents' desire to use the media for different purposes such as improving relations with friends or showing encouragement.

Table 1: Social Media Networks

Social Media	Description	Type
Facebook (2018)	Facebook is a status, picture, video, game, message and chat application.	Non-Episodic
Twitter (2018)	Twitter is a post, video, picture and message application.	Episodic
Snapchat (2018)	Snapchat is a picture, video and message application.	Episodic
Vine (2018)	Vine is a video sharing application. It contains a direct messaging feature for users to send to anyone as a SMS or email.	Episodic
Google+ (2018)	Google+ is a post, picture, video, message and multi-person video calls application.	Non-Episodic
Instagram(2018)	Instagram is a picture, video, chat and messaging application.	Episodic
Tumblr (2018)	Tumblr is a blogging tool containing multimedia and content. There is also a direct messaging feature called Fan Mail.	Non-Episodic
Pinterest (2018)	Pinterest is a bookmarking tool to post ideas of your own and to save different ideas of others.	Non-Episodic
LinkedIn (2018)	LinkedIn is a professional network where users post resume related information and connect with other users. It includes posting of status, pictures and links and sending messages. Users can endorse other users on different skills.	Non-Episodic
YouTube (2018)	YouTube is a company that allows "people to discover, watch and share originally-created videos. YouTube provides a forum for people to connect, inform, and inspire others across the globe and acts as a distribution platform for original content creators and advertisers large and small."	Non-Episodic

2.2. Online Socialability

Bakardjieva and Gaden (2012) examined the field of social interaction in general to the everyday chatter of unstructured and spontaneous interactions among individuals to highly structured and regulated interaction consisting of the military or the stock exchange. These researchers explored peer groups and the wider circle of people that user's on social media networks call "friends." Spies, Shapiro and Margolin (2014) suggests that adolescents with social media accounts begin and end their day by checking their friends' posts or creating posts of their own. Keenan and Ali (2009) performed a study to explore sociability on different social media websites specifically identifying how users interact on Facebook, LinkedIn, MySpace and Twitter. The findings provided details on how different social websites encourage their users to interact. Facebook focused on privacy and representing the real world but in an online environment as a user profile looks like a personal scrapbook. MySpace focused on publicity and representing both, the real world and virtual world, with promotion of an online persona from film to television to music. These profiles are media-rich profile pages best suited for public promotions although it does have a private setting should that be desirable for a user. LinkedIn focused on community with profiles looking similar to resumes as the site is primarily for professional networking. Twitter focused on technology with SMS-length updates on a simple user interface allowing users to provide quick and short status updates.

Educational institutions have an online socializing component through utilizing various technology. Podcasts are audio or video files for listening purposes, where the file itself plays on either a portable media player or personal computer (2006). Podcasting first became mainstream when used as a supplement to meet the needs of students whose learning disabilities required a multimodal form of knowledge acquisition (2008). Today's undergraduate students are members of Generation D, which tune into technologies for higher education (2006). These students of Generation D seek and utilize information in a manner unlike that demonstrated by previous generations of university students; for this group, culture and motivation, as well as learning styles and lifestyles, play an important role in information seeking (2006). In higher education, convenience drives the adoption of such online technologies both at and away from home (2016).

Businesses also utilize sociability online as it provides a means for business clients, academics, and industry analysts to communicate and collaborate (Iyer et al., 2016). Vuori and Okkonen (2012) suggests that collaborative settings in a work environment based on social media principles provides added value since employees can discuss different topics with the resulting outcome being enriched information. Research focus has also examined social media as a communication tool for businesses and as a tool for customers and businesses to interact (Lukinova et al., 2014; Baird & Parasnis, 2010). Heinonen (2011) focused on customers' engagement with a particular brand. Similarly, Harvey et al. (2011) studied how social media communications assist in the creation of networks and advocates. Cammaerts (2008) looked at the strategic implications of the use of social media on corporate communication management from the point of view of the end user. Jansen et al. (2009) explored social media as word of mouth advertising assisting with marketing of a company's products and services.

3. Methodology and Results

The study consisted of 209 respondents from a private university in the southeast US that participated in the study. The self-administered questionnaires were the survey instrument developed by the researchers. The majority of the respondents (85%) were between 18 and 25 years old with the percentage of males being 70%. The predominant category for ethnicity is White (American (44%)) and International (12%) comprising 56% of the respondents' ethnicity. Table 2 includes the full demographics of the respondents.

Table 2: Demographics (n=209)

Gender	Percent
Male	69.38%
Female	30.62%
Age	**Percent**
18 to 25 years old	85.46%
26 to 40 years old	10.57%
41 years and older	3.96%
Ethnicity	**Percent**
African American	8.61%
Hispanic American	8.13%
Asian American	2.39%
American White	44.02%
American Unspecified	0.48%
Asian	8.61%
African International	3.83%
White International	11.96%
International Unspecified	4.31%
2 or more races	7.66%

Social Media Frequency. The survey instrument presented a variety of social media brands; they included Snapchat, Twitter, Instagram, Google Plus, YouTube, Facebook, Vine, Tumblr, Pinterest, and LinkedIn. Using a Likert-type scale, recording of social media frequency included separate questions of "I use XXX frequently" with options ranging from a 1 (strongly disagree) to 5 (strongly agree).

Episodic Social Media. Several social media brands utilized in the survey considered Episodic Social Media—occurring occasionally and containing loosely connected parts. These brands consist of Snapchat, Twitter, Instagram, and Tumblr.

Attention Span. A five-item Likert-type scale based on Conners (2004) measured attention span on the survey instrument. Sample items included "I lose track of what I am supposed to do" and "I am distracted when things are going on around me." Response options ranged from 1 (strongly disagree) to 5 (strongly agree). The scale's alpha reliability is 0.786.

H1: The number of social media accounts has no relevance to the length of attention spans.

The study used a one-way ANOVA to test this hypothesis. The groupings of the participants were based on the number of social media accounts as low, medium, and high. The low number of accounts were 1 to 3 accounts (mean = 3.0143, variance = 0.666), medium of 4 to 6 accounts (mean = 2.965, variance = 0.624), and high of 7 to 10 accounts (mean = 3.027 and variance = 0.738).

The assessment was not statistically different showing there is no difference of the means of attention span from the groupings ($F(2, 206) = 0.1223$, $p > 0.05$). Thus, Hypothesis 1 is accepted.

H2: There is no difference of attention span length amongst frequent use of episodic social media and frequent use of non-episodic social media accounts.

An independent-samples t test compared the mean of the attention span scale for frequent users of episodic social media (mean = 3.093, variance = 0.567) with those who were more frequent users of non-episodic social media accounts (mean = 2.904, variance = 0.717). The comparison was found to not be statistically significant, $t = 1.710$, $p > 0.05$. Thus, Hypothesis 2 is accepted.

H3: There is no difference of attention span length amongst users preferring mobile versions of social media versus computer versions.

A one-way ANOVA was used to test this hypothesis. Groupings of the participants were based on the preference of using mobile versions of the application, computer-based versions of the application, or, overall, no preference. The mobile version's users' attention span mean is 2.999 (variance = 0.702), the computer-based versions users attention span mean is 2.979 (variance of 0.637), and the mean of the attention span for users who have no preference is 2.893 (variance of 0.685). The assessment was not statistically different showing there is no difference of the means of attention span from the groupings ($F(2, 713) = 0.923$, $p > 0.05$). Thus, Hypothesis 3 is accepted.

4. Conclusion

With the abundance of social media networks available at users' fingertips, social media is a component of individuals' lives that continues to affect how humans socialize contributing to the sociability phenomenon. The present study performed examined the number of social media accounts, frequency of use for episodic and non-episodic social media accounts and of their social media accounts and preference for mobile versions of social media versus computer versions in relationship to attention span length of users. The study findings accepted the three hypotheses. Research implications suggest that there is no difference between attention span lengths and the number of social media accounts, frequency of use or mobile versus computer preferences for accessing social media. The present study findings are important in research as it suggests the number or frequency of use of mobile devices or social media is not utilized more by those with short attention spans. The study benefits the area of industrial engineering and management through understanding how social media networks can affect users in both personal and business environments. One area of industrial engineering is human factors that focuses on negative or positive impacts of humans interacting with technology. This research benefits the area of human factors and management through the findings that suggest that the number or frequency of use of mobile devices or social media is not utilized more by those with short attention spans.

The researchers identified future research areas. One area to explore further is to understand the type of users drawn to episodic and non-episodic social media tools. This would assist businesses with which social media applications to use for advertising to specific consumers. It would be beneficial to educational institutes in helping students' access supplemental classroom materials through identification of the types of tools students use. Research focused in learning the depth that social media can play in enhancing education for students, customer relationships with companies and employee relationships with their peers are specific areas to explore. Social media networks are increasing so understanding how to utilize this social media epidemic to enhance learning, relationships and business knowledge is essential as individuals are spending an increasing amount of time on these episodic and non-episodic networks. Further research should be conducted to further explore the area of industrial engineering and management to expand upon the knowledge of positive and negative user impacts from social media network usage from both a personal and professional perspective. Social media makes individuals feel as though they have a star movie role (Bochenek & Blili, 2014). Therefore, who would not want to have a "role" in this social media craze? Social media networks have become an imprint of our everyday life and part of pop culture that revolutionize the way people communicate and in the way organizations communicate and act. Social media is a component of individuals' lives that continues to affect how humans socialize contributing to the social media phenomenon that is a growing social craze.

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Examining Practices, Barriers, and Contextual Issues in the Literature of Lean Supply Chain Management

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Abstract

The incorporation of lean principles and practices into supply chain management (SCM) brings about benefits to the manufacturing industry, what is called lean supply chain management (LSCM). This results in differentiated outcomes along the supply chain, surpassing those already achieved by the organizations individually. In this context, this paper aims at identifying practices, implementation barriers, and contextual issues of LSCM, through a systematic literature review. After searching relevant data bases of peer-reviewed publications, 60 articles were retrieved and analyzed. The content of extant LSCM literature was then synthesized from the perspective of the practices, barriers, and contextual factors inherent to LSCM implementation. There has been a sharp increase in studies related to LSCM. Eighteen practices, twelve barriers, and eight contextual factors inherent to LSCM implementation were consolidated. Most studies on LSCM have focused on outlining practices and their potential benefits, inferring that once companies adopt them the lean implementation would be automatically started. Nevertheless, such implementation throughout the supply chain is extremely difficult and challenging. This study may then help researchers and practitioners to anticipate difficulties and set the proper directions along the LSCM implementation.

1. Introduction

A number of factors have driven organizations to apply new concepts that support supply chain effectiveness. Having an appropriate Supply Chain Management (SCM) program is a key factor for companies, since it impacts their operational performance in terms of lower inventory level, more efficient processes, reduced costs, enhanced service level delivery, and higher customer satisfaction (Ugochukwu et al., 2012). To assure competitiveness, an organization should produce the right products, with the expected quality and quantity, at the right price and time, for the right customer (Jasti and Kodali (2015a). In this context, the integration of lean principles and practices into SCM has achieved outcomes along the supply chain, surpassing those already realized by the individual organizations (Arif-Uz-Zaman and Ahsan, 2014).

Lean Supply Chain Management (LSCM) is a set of organizations directly linked by upstream and downstream flows of products, services, finance, and information that work collaboratively aiming at cost and waste reduction in an efficient way (Vitasek et al., 2005). Many studies have addressed LSCM (e.g. Li et al., 2006, Boonsthonsatit and Jungthawan, 2015). Nevertheless, most of them are restricted to certain industrial sectors, dealing with few lean practices, and neglecting a holistic perspective inherent to the LSCM implementation. Several modifications should be made to adapt lean principles and practices to SCM (Anand and Kodali, 2008). While manufacturing predominantly involves the flow of materials with a reduced amount of information within the boundaries of the organization, the supply chain comprises the flow of materials, information, and resources beyond the boundaries of the organization. Thus, both the benefits and the barriers faced for LSCM implementation may differ from those already known in manufacturing (Manzouri and Rahman, 2013). Moreover, contextual factors that may influence the implementation of LSCM are scarcely evidenced in the literature if compared to studies in manufacturing environments (Li et al., 2006).

In this sense, two research questions can be raised: (i) what are the main practices of LSCM", (ii) what are the inherent barriers and the contextual factors that influence the LSCM implementation?" Thus, the objective of this work is to identify the main LSCM practices, barriers to such implementation, and contextual factors that influence it through a literature review. This paper is structured as follows. Section 2 describes the research methods, whose results are discussed in section 3. Finally, section 4 draws some concluding remarks and directions for future research.

2. Research design

The methodological approach consists of the steps are shown in Figure 1.

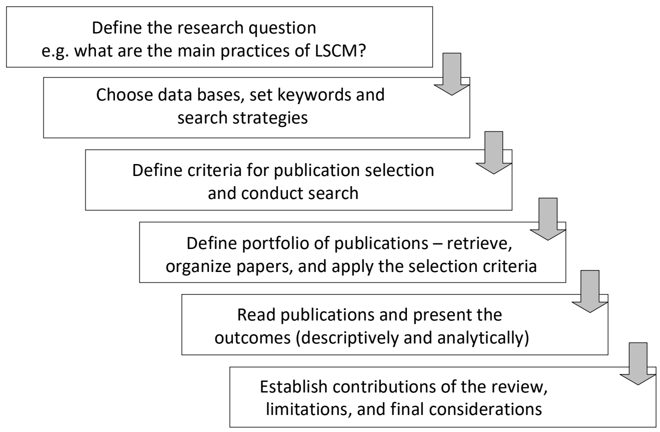

Figure 1. Literature review process

The first step defines the research question that the paper will seek to address. This served as the starting point for conducting a systematic literature review. This study addressed the research questions presented in the introduction. Then, in the second step, the databases were chosen. The strategy for the selection of databases considered the following information needs (Lancaster, 2004): (*i*) coverage (how complete is the content of the database in the subject); (*ii*) recoverability (how many documents on the subject can be found in the database using a search strategy that is not very complex); (*iii*) predictability (the researcher can verify the relevance of the documents from the information contained in the database; and (*iv*) actuality (frequency in adding new publications in the database). Three bases were then decided on: Emerald, Scopus, and Web of Science.

The following criteria were established for selecting the publications in the third step: (*i*) discard duplicates and non-articles, and (*ii*) alignment of articles' titles, abstract, and full texts with the research subject. Then, a search was performed in the databases based on the selected keywords and strategy. Step four carried out an analysis of the initial portfolio. Publication files were exported to the EndNote X7® to assist with their organization and management. EndNote is a useful tool for publishing and managing bibliographies, citations, and references when dealing with literature analysis. This reference management software not only assists the researcher from the tedious work of manually collecting and curating your research materials and formatting bibliographies, but also offers to him/her greater ease and control in coordinating with colleagues (Clarivate Analytics, 2018). The choice of this software also occurred because the databases already have the option to export the metadata of publications to Endnote, thus facilitating the obtaining data for subsequent content analysis of articles. Subsequently, the criteria defined in step three were applied, so excluding those that were not aligned with the research subject and objectives. After that, 60 publications were available for analysis. In the fifth step, two authors read those set of articles in full and extracted relevant data aligned with the purpose of this work. Finally, step six established the contributions of this study, as well as possibilities for continuing this research. Table 1 shows the total selected articles that consisted of the final portfolio of publications.

Table 1. Keywords, data bases, and number of publications

	Quantitative databases		
Keywords	***Emerald***	***Scopus***	***Web of Science***
"*lean supply*" AND *"practices"* OR *"implement"*	234	58	25
"*lean supply*" AND "*failures*" OR "*challenges*" OR "*barriers*"	175	40	8
"*lean supply*" AND "*contextual factors*"	189	8	18
"*lean supply*"	282	236	111
Total at each data base	**880**	**342**	**162**
Total (preliminary portfolio of publications)	**1,384**		
Duplicate publications or non-articles	867		
Articles not related to the objective of this work (title and abstract)	401		
Articles not related to the objective of this work (full text)	56		
Total selected articles (Final Portfolio)	**60**		

3. Results and discussion

3.1. Descriptive analysis of the publications

The allocation of the publications in the researched period (1996–2017) is shown in Figure 2.

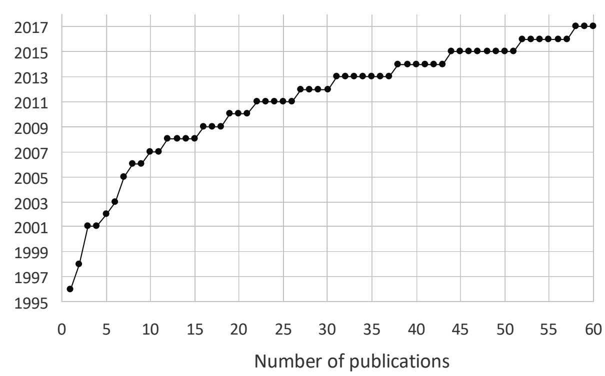

Figure 2. Distribution of publications (n=60) across the selected period (1996-2017)

Considering the evolution in time in Figure 2, although the lean principles and practices became popular in the 1990s, their implementation in the supply chain context gained more attention a few years later (Ugochukwu et al., 2012). The understanding of lean principles and practices has undergone an evolution over the years, starting from the approach focused on plant floor tools to a contingent perspective along the value chain (Hines et al., 2004). This fact can be noted, since the first article related to the subject was published in the middle nineties by Lamming (1996), with a discrete increase of publications in the following years. After 2011, a significant increase in the number of publications has been noticed related to the subject, with highest number of publications (8 articles) in 2015.

The LSCM literature has three journals offering almost one-third of the papers. The leading journal is the Supply Chain Management: an International Journal with 8 papers, followed by the International Journal Accounts and Production Planning & Control with 6 papers each. This study also pointed out supply chains in different sectors, such as, agribusiness (Perez et al., 2010), automotive (Wee and Wu, 2009), electronics (McIvor, 2001), food (Vlachos, 2015), toys (Yew Wong et al., 2005), etc. Some supply chains still have, however, a shortage of studies, as suggested by Cudney and Elrod (2011).

Regarding the nature of research approaches, applied research prevailed in most of them (70%) being the remainder theoretical. Applied research is usually focused on solving practical issues (Vilaça, 2010), while the theoretical research is essentially based on a literature review, position papers, or proposals of a theoretical framework. Moreover, among the 42 applied research articles, 15 corresponded to studies in the context of emerging economies, while 14 were in developed countries (the others did not mentioned the context).

3.2. LSCM practices

Lean practices can be applied across the entire supply chain, from placing the order with suppliers to distributing and delivering the product to the end customer. Previous studies (e.g. Perez et al., 2010, Manzouri, 2012; Hartono et al., 2015; Vlachos, 2015) associate the implementation of LSCM practices with improvements in the supply chain operational performance, regardless of its context. Erridge and Murray (1998), for instance, indicate benefits such as reduction of inventory, increase of service quality, cost reduction, and better relationship between suppliers and customers. Nevertheless, studies on LSCM practices are still less frequently evidenced in the literature if compared to manufacturing environments. The implementation of LSCM practices in services is considered more complex than manufacturing (Martínez-Jurado and Moyano-Fuentes, 2014), since it requires a significant adaptation and involves different companies (Manzouri et al., 2014). In this sense, most of the studies that address LSCM practices indicate the need for leadership restructuring and establishment of a supporting infrastructure (Behrouzi and Wong, 2011, Vlachos, 2015). It is worth noticing that there are some industrial sectors little explored regarding the progress of LSCM implementation, in which different challenges and benefits may emerge than those already expected (Cudney and Elrod, 2011).

Of the 60 publications, 55 addressed some kind of LSCM practice. Table 2 shows the most cited LSCM practices (P) among these publications. As can be seen, the citation frequency of those 18 practices presents variations. Practices P_1 (Kanban or pull system) and P_2 (Close relationship between customer, supplier, and relevant stakeholders) are in the top two most frequently cited in the LSCM studies (38 and 32, respectively). The high frequency of citations can be explained by the fact that these practices are included in the precursor studies of LSCM (e.g. Lamming, 1996, Erridge and Murray, 1998), since their impact on both manufacturing process and supply chain performance can be more easily perceived. In fact, these practices were consistently associated with the LSCM studies over time, leading to a high number of research evidence that reports their application. Specifically for P_1, McIvor (2001) argued about its impact on obtaining lower inventory levels and greater visibility of quality problems. In addition, such practice is commonly associated with just-in-time (JIT) deliveries (Wiengarten et al., 2013), in which the right material is delivered at the expected time, place, and quantity (Qrunfleh and Tarafdar, 2013). Consequently, the adoption of P_1 implies a narrowing of information and material flows between suppliers and customers, reinforcing the collaboration between them (P_2) (Martínez-Jurado and Moyano-Fuentes, 2014). In this sense, it is reasonable to expect that both P_1 and P_2 present high recurrence of citations over time, since they are closely related (Bhamu and Singh Sangwan, 2014). On the other hand, P_{18} (establishment of distribution centers) was the least mentioned practices out of 55 studies. Taylor (2006) appears to be the first study to suggest the incorporation P_{18} into the set of LSCM practices. However, P_{18} was explicitly included in the set of LSCM practices in the work of Sharma et al. (2015) and Jasti and Kodali (2015a).

The 18 practices in Table 2 offer a representative view of the main practices adopted in LSCM. The approach of analyzing the impact of lean implementation based on the assessment of the adoption level of pre-defined practices has been widely used in previous studies (e.g. Qi and Chu, 2009, Rahman et al., 2010, Manzouri et al., 2013, Sharma et al., 2015). This seems to be effective in understanding the maturity of companies regarding LSCM.

Table 2. LSCM practices in the literature

Practices (P_n)		Frequency	References
P_1	*Kanban* or pull system	38	[1], [2], [4], [7], [9], [12-15], [17-22], [24], [25], [27-30], [32], [34], [35], [37-41], [43], [44], [46-48], [50], [52], [53], [55]
P_2	Close relationship between customer, supplier and relevant stakeholders	32	[1], [2], [4-6], [9], [11], [12], [14-16], [19], [20], [22], [23], [26], [28], [29], [32-38], [40], [43], [44], [46], [49], [54], [55]
P_3	Use of information technology to share and integrate the flow of information along the supply chain (e.g. EDI, RFID, ERP, etc.)	26	[2], [4], [6-9], [12-14], [16], [18], [20], [21], [23], [26], [28], [29], [34], [38], [40], [43-45], [48], [54], [55]
P_4	Efficient and continuous replenishment	25	[1], [7], [9], [13], [17-22], [25], [28], [29], [31], [34], [35], [37], [38], [41], [44-46], [50], [52], [53]
P_5	Continuous improvement	24	[2], [5], [13], [14], [15], [17], [20], [22], [29], [30], [32], [33], [37], [38], [40], [41], [44-48], [50], [51], [54]
P_6	Value chain analysis or Value stream mapping	23	[9], [10], [13], [14], [17], [22], [24], [27], [29], [30], [35], [37-39], [41], [42], [44-48], [50], [54]
P_7	*Keiretsu* (relationship based on trust, cooperation and educational support, suppliers play an important role in the organization)	21	[1], [2], [8], [9], [12], [14], [16], [18], [19], [23], [25], [26], [28], [32], [35], [36], [43], [44], [46], [49], [51]
P_8	Supplier managed inventory (consigned)	20	[1], [5], [9], [12], [14], [16], [19], [21], [25], [26], [32], [33], [35], [39], [40], [43], [44], [46], [48], [54]
P_9	Distribution logistics	18	[1], [4], [11], [13], [14], [16], [23], [26], [27], [29], [32], [43-46], [48], [51], [54]
P_{10}	Standardized work procedures to assure quality achievement	17	[11], [12], [14], [17], [20], [24], [37-41], [43-45], [50-52]
P_{11}	Frequent participation from the beginning of new product development process	13	[2], [3], [4], [6], [12], [20], [23], [33], [36], [44], [46], [49], [51]
P_{12}	*Hoshin Kanri* (development of strategies and commitment and support of the top managers)	12	[1], [5], [9-12], [20], [26], [36], [37], [44], [51]
P_{13}	Development of supply chain KPIs	12	[8], [9], [11], [15], [20], [25], [30], [35], [44-46], [51]
P_{14}	Leveled scheduling or *heijunka*	10	[1], [13], [17], [24], [37], [38], [44-46], [55]
P_{15}	*Kyoryoku Kai* (association of suppliers working together to develop more efficient methods of work reducing waste)	8	[1], [9], [14], [20], [28], [44], [48], [53]
P_{16}	Problems solution (frequent feedback working together for shared solutions)	7	[4], [19], [36], [37], [44], [46], [52]
P_{17}	Value chain management	7	[9], [13], [14], [20], [44], [46], [47]
P_{18}	Establishment of distribution centers	3	[9], [44], [46]

Refs.: [1] Lamming (1996); [2] Erridge and Murray (1998); [3] McIvor (2001); [4] Arkader (2001); [5] Huang *et al.* (2002); [6] Birgün Barla (2003); [7] Yew Wong *et al.* (2005); [8] Jaklic *et al.* (2006); [9] Taylor (2006); [10] Eisler *et al.* (2007); [11] Morgan (2007); [12] Machado and Pereira (2008); [13] Adamides *et al.* (2008); [14] Anand and Kodali (2008); [15] Found *et al.* (2008); [16] Qi and Chu (2009); [17] Wee and Wu (2009); [18] Parveen and Rao (2009); [19] Stavrulaki and Davis (2010); [20] Perez *et al.* (2010); [21] Rahman *et al.* (2010); [22] Parveen *et al.* (2011); [23] Gueimonde-Canto *et al.* (2011); [24] Cudney and Elrod (2011); [25] Carvalho *et al.* (2011); [26] Manzouri (2012); [27] Al-Aomar (2012); [28] Azevedo *et al.* (2012); [29] Drohomeretski *et al.* (2012); [30] Karim and Arif-Uz-Zaman (2013); [31] Camacho-Minano *et al.* (2013); [32] Manzouri and Rahman (2013); [33] Qrunfleh and Tarafdar (2013); [34] Wiengarten *et al.* (2013); [35] Dües *et al.* (2013); [36]

Martínez-Jurado and Moyano-Fuentes (2014); [37] Hadid and Mansouri (2014); [38] Bhamu and Singh Sangwan (2014); [39] Arif-Uz-Zaman and Ahsan (2014); [40] Manzouri *et al*. (2014); [41] Jasti and Kodali (2015a); [42] Boonsthonsatit and Jungthawan (2015); [43] Hartono *et al*. (2015); [44] Jasti and Kodali (2015b); [45] Olesen *et al*. (2015); [46] Sharma *et al*. (2015); [47] Vlachos (2015); [48] Adebanjo *et al*. (2016); [49] Jajja *et al*. (2016); [50] Dora *et al*. (2016); [51] Soni and Kodali (2016); [52] Marodin *et al*. (2016); [53] Carvalho *et al*. (2017); [54] Duarte and Machado (2017); [55] Bevilacqua *et al*. (2017).

3.3. Barriers for LSCM implementation

The LSCM implementation, like any other continuous improvement initiative, entails enormous difficulties (Rahman *et al.*, 2010). Although LSCM has been applied in different sectors, a few questions remain unaddressed due to the inherent supply chain complexity and longer term results, entailing additional challenges to improvements implementation throughout the chain (Adebanjo et al., 2016).

From the 60 articles retrieved, about half of them addressed some kind of barrier inherent to the LSCM implementation. Out of those, only four publications explicitly presented the barriers and challenges of LSCM as the main subject (McIvor, 2001, Manzouri et al., 2013, Jadhav et al., 2014, Dora et al., 2016). The other articles shallowly approached a few barriers resulting from the application of LSCM practices (e.g. Arkader, 2001, Anand and Kodali, 2008, Perez *et al.*, 2010, Adebanjo *et al.*, 2016). Vlachos (2015) reported the lack of involvement of top management in the improvement projects, implying a limited and failed implementation. Jadhav et al. (2014) stated that the only way to create a truly lean transformation is through strong leadership at the top of the organization, including the CEO. The actual involvement of top managers is in fact fundamental to support and sustain improvements (Yew Wong *et al.*, 2005). In turn, lack of commitment may lead to a number of issues, such as limited access to resources, lengthy decision-making processes, and communication failures (Perez *et al.*, 2010).

Another relevant aspect to be considered is the team development, which is usually focused on developing training on lean principles and practices, empowering employees with the required knowledge and skills (Karim and Arif-Uz-Zaman, 2013). As lean implementation becomes reasonably consolidated within the organization (shop floor and business processes), most companies extend training to agents of their supply chain (Cudney and Elrod, 2011). However, the extension of LSCM implementation tends to be initially focused on upstream agents (suppliers) and their practices (Bevilacqua et al., 2017). Thus, the existence of specialized teams for training and qualification on LSCM practices allows greater proximity with supply chain agents, establishing a development process that goes beyond the traditional issues related to price and delivery (Dües et al., 2013, Martínez-Jurado and Moyano-Fuentes, 2014).

In addition, Manzouri et al. (2013) identified that the lack of trust among supply chain agents (suppliers and customers) is an important barrier to overcome, as it undermines the information sharing process. Taylor (2006) argued that there is a difficulty in moving away from current negotiation strategies, which is characterized by seeking profit maximization in the short term. Such strategies negatively influence the establishment of long-term partnerships and reinforce power-based relationships that jeopardize LSCM implementation (Perez et al., 2010). Enhancing trustful relationships among these agents also mitigates the risks to all parties. Therefore, it is reasonable to assume that these agents depend on each other to obtain higher levels of operational performance (Manzouri et al., 2014).

Table 3 displays the underlying barriers (B) to LSCM implementation from 34 articles. It is worth noticing that there is a variable citation frequency for each barrier. In general, the 12 barriers showed in Table 3 emerged from this literature review and provided a representative view of the main barriers inherent to LSCM implementation. The identification of these barriers can then be a starting point to properly addressing the difficulties, allowing the anticipation of a few of them (Jadhav et al., 2014).

Table 3. LSCM barriers and their frequency of citation in the literature

Barriers		Frequency	Refs
B_1	Difficulties for cultural changes	26	[1-3], [4], [5], [6], [8], [10], [11], [13], [14], [16-18], [20-26], [28], [30-34]
B_2	Lack of commitment of senior management	22	[1], [5], [6], [8-13], [16-19], [22-24], [26], [27], [29], [30], [32], [33]
B_3	Lack of specialized team development	21	[8], [10], [13], [16-19], [21-34]
B_4	Lack of trust in supply chain partnerships	14	[1], [3-5], [7], [8], [12], [16], [18], [22], [24], [26], [27], [31]
B_5	High oscillation of demand	11	[5-8], [10], [14-16], [21], [26], [34]
B_6	Low information sharing	11	[3], [5], [7], [8], [17], [23], [24], [27], [30], [32], [34]
B_7	Lack of collaboration and involvement of the entire supply chain	10	[4], [6-9], [12], [13], [20], [23], [24]
B_8	Lack of availability of resources	10	[4], [8], [19], [21], [22], [24], [27], [30], [32], [34]
B_9	Lack of Information and Communication Technology (ICT) infrastructure for integration	10	[6], [7], [12], [13], [18], [23], [27], [30], [32], [33]
B_{10}	Resistance to joining long-term strategies	6	[3], [14-18]
B_{11}	Complexity of the supply chain	6	[1], [7], [11], [14], [15], [22]
B_{12}	Low understanding of concepts and principles related to LSCM implementation	3	[13], [19], [22]

Refs.: [1] Lamming (1996); [2] Erridge and Murray (1998); [3] McIvor (2001); [4] Arkader (2001); [5] Huang *et al*. (2002); [6] Yew Wong *et al*. (2005); [7] Jaklic *et al*. (2006); [8] Taylor (2006); [9] Eisler *et al*. (2007); [10] Morgan (2007); [11] Machado and Pereira (2008); [12] Adamides *et al*. (2008); [13] Anand and Kodali (2008); [14] Wee and Wu (2009); [15] Stavrulaki and Davis (2010); [16] Perez *et al*. (2010); [17] Cudney and Elrod (2011); [18] Behrouzi and Wong (2011); [19] Manzouri (2012); [20] Azevedo *et al*. (2012); [21] Karim and Arif-Uz-Zaman (2013); [22] Manzouri *et al*. (2013); [23] Martínez-Jurado and Moyano-Fuentes (2014); [24] R. Jadhav *et al*. (2014); [25] Hadid and Mansouri (2014); [26] Bhamu and Singh Sangwan (2014); [27] Manzouri *et al*. (2014); [28] Tortorella *et al*. (2015); [29] Vlachos (2015); [30] Adebanjo *et al*. (2016); [31] Jajja *et al*. (2016); [32] Dora *et al*. (2016); [33] Kumar *et al*. (2016); [34] Bevilacqua *et al*. (2017).

3.4. Contextual factors for LSCM implementation

Contextual factors are aspects that correspond to specific characteristics of a company or its environment, such as number of employees, sales volumes, sector, time in which a management system is implemented, and others (Hadid and Mansouri, 2014). Further, these factors represent situational characteristics usually exogenous to the focal organization or manager (Tortorella et al., 2015). A number of contextual factors are inherent to each supply chain and may affect the relationship between the cooperation level of its agents and their performance (Gueimonde-Canto et al., 2011). However, the modification of these factors tends to be limited and only possible with a long-term effort (Manzouri et al., 2013). Thus, taking into account their influence is vital for a better understanding of the LSCM implementation (Camacho-Minano et al., 2013).

A proper selection of LSCM practices depends on the context of each company and its supply chain (Karim and Arif-Uz-Zaman, 2013). Therefore, the strategy for the transition from a traditional supply chain model to a LSCM cannot be indiscriminately generalized, since the different contextual factors are determinant for such a decision (Rahman et al., 2010). Table 4 summarizes the contextual factors (CF) inherent to LSCM implementation. Half of the articles addressed CF. It is worth noticing that the total frequency of citation and the number of articles that addressed the subject was significantly lower than those that approached LSCM practices and barriers.

The contextual factor CF_1 (company size) was the most cited factor (63% of the articles). Larger companies are more likely to have higher adoption levels of LSCM practices, since they usually have a more complex supply chain and, hence, need a more efficient management (Hadid and Mansouri, 2014). Company size is positively associated with LSCM implementation, since larger organizations presuppose higher bargaining power and leadership within the supply chain to which they belong (Manzouri, 2012). In turn, the contextual factor CF_8 (production volume) was the least cited among the publications (7%). High production volumes generally imply a greater prominence of the company within its supply chain. Such importance can affect the way in which the relationships between the company and its customers and suppliers are established, given the greater implicit bargaining power (Lamming, 1996). Many studies adopt a fragmented approach to LSCM implementation, ignoring their systemic nature and resulting in their failure (Dora et al., 2016). The eight CF found from the literature review may provide a representative view of the LSCM implementation. The identification of these CF, as well as their effect on LSCM implementation, is essential for the adaptation and customization of the improvement strategies adopted.

Table 4. Contextual Factors in the LSCM literature

Contextual Factors		Frequency	Refs
CF_1	Company size	19	[3], [6], [8-11], [13], [14], [16-18], [21-24], [26-28], [30]
CF_2	Trained multifunctional team	11	[2], [4], [6], [10], [12], [13], [16], [22], [24], [27], [29]
CF_3	Geographic location	10	[1], [3], [5], [7], [12], [13], [15], [20], [25], [26]
CF_4	Supply chain sector	8	[8], [12], [13], [15], [17], [18], [25], [27]
CF_5	Country's socio-economic factors	8	[1], [3], [7], [15], [17], [18], [26], [28]
CF_6	Educational level	6	[1], [2], [10], [16], [19], [24]
CF_7	Plant age	3	[21], [24], [26]
CF_8	Production volume	2	[16], [27]

Refs.: [1] Arkader (2001); [2] Huang *et al*. (2002); [3] Taylor (2006); [4] Machado and Pereira (2008); [5] Adamides *et al*. (2008); [6] Anand and Kodali (2008); [7] Found *et al*. (2008); [8] Qi and Chu (2009); [9] Wee and Wu (2009); [10] Perez *et al*. (2010); [11] Rahman *et al*. (2010); [12] Gueimonde-Canto *et al*. (2011); [13] Cudney and Elrod (2011); [14] Manzouri (2012); [15] Azevedo *et al*. (2012); [16] Karim and Arif-Uz-Zaman (2013); [17] Camacho-Minano *et al*. (2013); [18] Manzouri *et al*. (2013); [19] Martínez-Jurado and Moyano-Fuentes (2014); [20] R. Jadhav *et al*. (2014); [21] Hadid and Mansouri (2014); [22] Bhamu and Singh Sangwan (2014); [23] Manzouri *et al*. (2014); [24] Tortorella *et al*. (2015); [25] Adebanjo *et al*. (2016); [26] Jajja *et al.* (2016); [27] Dora *et al*. (2016); [28] Marodin *et al*. (2016); [29] Duarte and Machado (2017); [30] Bevilacqua *et al*. (2017).

4. Conclusions

Most of the studies cited in this research have focused on outlining practices and their potential benefits, inferring that once companies adopt them the lean implementation would be automatically started. Nevertheless, such implementation throughout the supply chain is challenging. The present study aimed to identify the main practices, barriers, and contextual factors inherent to the LSCM implementation. To achieve that, a systematic literature review was undertaken. It may contribute to the LSCM body of knowledge on LSCM, by consolidating 18 practices, 12 barriers, and 8 contextual factors inherent to its implementation. From the analysis, most research addressed the three topics (practices, barriers, and contextual factors) individually. This work showed that there is still a certain degree of superficiality concerning the understanding of LSCM-specific practices, since many of those are mixed with manufacturing practices and do not undergo the adaptations needed to support the complexity of a supply chain. This paper also pointed out that few studies have addressed an holistic view of LSCM. Many researchers have focused on analyzing aspects of LSCM practices upstream of the supply chain, while few articles have analyzed downstream practices. Moreover, the identification of the main barriers inherent to LSCM implementation allows adopting preventive counter measures to mitigate potential barriers associated with the supply chain context under study, entailing a less problematic LSCM implementation. Thus, future work will look into the relation between barriers and supply chain contextual factors possibly through an in-depth multiple case study.

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Measuring the Digital Divide in Interactive Communication

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Abstract

Digital divide is a consequence of differences among countries, social groups and organizations with regard to their access to computer and communication systems, hardware, software and applications. It creates barriers and impediments to communication. The purpose of this paper is to present a new way of measuring digital divide in interactive communication. Scope and extent of digital divide is analyzed at different levels of aggregation. Proportion between levels of access to and practical use of digital technology in different countries, social groups and organizations is an indicator of scale of the digital divide. The digital divide quotient (DDQ) has been proposed and defined as a quotient of numbers (measures) reflecting levels of access to and practical use of digital technology in respective two countries, social groups or organizations. To better illustrate this concept some specific elements of digital technology are taken into consideration such as: Internet, broadband transmission, smartphones, social media/networks, messengers etc. The digital inequality factor (DIF) is also proposed to reflect the extent of DDQ differences under certain conditions. Examples of digital divide quotient and digital inequality factor are presented. They are used for illustration of international and local/social digital divides. Suggestions concerning the directions of further research on methods of measurement are combined with conclusions.

1. Introduction

The purpose of this paper is to propose a new approach to measuring the scale and properties of digital divide in interactive communication. From an historical perspective, the digital divide may be viewed as a phenomenon being part of inequality in technological development. In the 1960's, the concept of *technological gap* was launched in the context of international trade, prices of products and services, and productivity (Posner, 1961). That gap was measured by differences in performance quality parameters of products and services. Later, in the 1980's, the concept of *technological delay* was used suggesting that essential technologies advance along similar patterns in different countries i.e. less developed countries reproduce the path of technology advance but with a certain delay that is measurable in years. This approach was reflected in R&D programs of certain firms and industrial strategies at the national level (e.g. in Japan) aimed at *technological catch-up* with the leaders in respective technologies (Pelc, 1986). Finally, since the early 21st century, the focus of analysis shifted to differences and inequalities in digital technologies as reflected by different scales of *access to, adoption and impact* of those technologies (hardware, software, systems) in societies (Van Dijk and Hacker, 2003). The latter approach, specifying three elements of the digital divide definition is used in this paper for assessment of inequalities with regard to interactive communication. An additional aspect should be mentioned here. The digital divide in communication may refer to such subjects as individuals (interpersonal, intergenerational etc), organizations (divisions, groups, functional areas etc), or countries (international, global etc). At the same time it may be considered as a consequence of different rates of diffusion/adoption of innovation in digital technologies. Selection of literature on measurement of the digital divide is presented below as a background for the proposed new approach applicable to measuring of the digital divide in interactive communication.

From among large number of publications on the subject of the digital divide, the following four have been selected for review as the most relevant to measurement and assessment of scale of this multidimensional phenomenon.

An overview of measurement problems related to the digital divide has been presented by Corrocher and Ordanini (2002). The authors focus attention on the "cross-country differences" in three factors of digitization: communication infrastructure, human resources, and competitiveness/competition of providers. They identified 36 elementary indicators of divide e.g. number of devices connected, penetration of broadband Internet, employment in IT, Internet access costs. An aggregation method has been proposed based on a linear combination of those indicators with respective weights allowing for calculation of one *synthetic index of digitization*.

Van Dijk and Hacker (2003) emphasized complexity and dynamics of the digital divide. They identified 4 barriers to access: *mental* access i.e. lack of elementary digital experience, *material* access i.e. no possession of computers and networks, *skill* access i.e. insufficient user friendliness and inadequate education, and *usage* access i.e. lack of usage opportunities. The authors presented comparative data on the U. S. and the Netherlands for three indicators: possession of computers, skills, and use of IT and their dependence on 4 variables: income, education, age and gender. Qualitative synthesis of those data has been described without introducing an aggregated index of digital divide.

A digital divide model has been discussed by Abdalhakim (2009) together with a definition and measurement of the *digital divide gap.* The author proposed four criteria for that measurement: *diffusion* of computing power (availability), *infusion* of computing power (installation and usage), computing *interpretability yield* (of combined hardware – software resources), and computing power *functionality* (users' acceptance). Application of this analytical approach is focused on the digital divide within an enterprise (divided among organizational units or divisions). The digital divide gap is represented as the difference between the benchmark digital status and the current digital status. Calculation of the "gap" is based on an algorithm involving three matrices of data representing hardware, software and user's satisfaction.

Analysis of the digital divide presented by Pick and Nishida (2015) is focused on effects of technology utilization at the global scale and in geographical regions. Two aspects are emphasized: geographical clustering of technological innovations and cross impacts within and between regions. Those regions are described with clear distinction of developed and developing countries. The authors specified 14 variables characterizing social, economic and technological situations reflecting the digital divide. Those variables are later aggregated into 5 *group factors* such as: personal computers, Internet users, broadband subscribers, secure Internet servers, and mobile telephone subscribers. The concept of *spatial interactions and clusters* in technology utilization is illustrated by the case of regional influences in Scandinavia. Changes in digital divide are described with emphasis on socio-economic factors such as impact of higher education, societal openness, and foreign direct investment.

In summary, all authors demonstrated complexity of the digital divide as an object of research. Almost all of them used a large number of parameters to assess scale of the phenomenon under consideration. Some publications suggest aggregation of measured (or assessed) specific factors as the way to determine the existence and scale of the digital divide. Two new aggregate measures are proposed below in order to simplify and better represent fundamental effects of the digital divide: digital divide quotient and digital inequality factor.

2. Methodology

2.1. Digital divide quotient

The proposed method of digital divide measurement is based on the following assumptions:

(a) The measurement should allow a pair-wise comparison of representative variables or indices

(b) Representative variables or indices should be selected to characterize the interactive communication systems

(c) The measure should be in the form of a simple, approximate and easy to calculate index

(d) It should be a multiplicative representation of scale of the digital divide, instead of differential measures of the gap.

The new measure called *digital divide quotient (DDQ)* satisfies those assumptions. It is a numerical index calculated as a proportion between values of respective parameters representing essential characteristics of digital divide in interactive communication between subjects (countries, social groups, organizations, individuals etc).

If d_1 and d_2 are parameters of digital divide of a pair of subjects, then

$DDQ = d_1/d_2$ digital divide quotient for the pair

hence if $d_1 = d_2$ then DDQ =1.

For illustration, examples of data sets for digital divide quotient are presented in Tables 1 and 2.

Table 1. Digital divide quotient (DDQ)
International comparisons with the U. S.: Penetration of four selected technologies in population
DDQ calculated on basis of data extracted from: www.internetworldstats.com, www.pewglobal.org

U.S. /country	Internet (2017)	Smartphones (2015)	Facebook (2017)	WhatsApp (2016)
U.S./Japan	0.93	1.84	3.57	n.d.
U.S./China	1.65	1.24	n.d.	n.d.
U.S./Germany	0.98	1.20	1.91	0.29
U.S./Russia	1.15	1.60	n.d.	n.d.
U.S./S. Korea	0.95	0.82	2.19	n.d.
U.S./India	2.55	4.23	4.11	0.57
U.S./Ethiopia	5.70	18.00	17.09	n.d.
U.S./Uganda	1.92	18.00	14.13	n.d.
U.S./Malaysia	1.11	1.11	1.20	0.26

n.d. = no data available

The DDQ values in Table 1 indicate that the U.S. is leading (among the selected countries) in penetration of smart phones except for South Korea (DDQ < 1) and in penetration of Facebook. However, the U.S. is behind three countries in penetration of WhatsApp: Germany, India, and Malaysia. The number of WhatsApp users as percent of population in Malaysia is almost 4 times larger than in the U. S. (DDQ= 0.26). It should be noted that data on that technology penetration were not available for several countries at the time of this study. It is also possible to note that the penetration of all technologies under consideration was lowest in Ethiopia (e.g. 18 times less smartphones per capita than in the U. S, and 5.7 times less Internet users as percent of population).

Table 2. Digital divide quotient (DDQ) by age group in different countries
Smartphone ownership by % of age group population (2015)
DDQ calculated on basis of data extracted from: www.pewglobal.org

Country	Millennials age 18-34 d_1 = owners as % of population	All people older than millennials: age 35 + d_2 = owners as % of population	DDQ Digital divide quotient for country's population
U. S.	92	65	1.41
Japan	77	31	1.84
China	85	43	1.97
Germany	92	50	1.84
Russia	76	29	2.62
S. Korea	100	83	1.20
India	27	9	3.00
Ethiopia	n.d.	n.d.	n.d.
Uganda	6	2	3.00
Malaysia	88	46	1.91

d_1 and d_2 = smartphone owners as % of the age group population
Digital divide quotient DDQ = d_1/d_2

Data presented in Table 2 show differences in scale of digital divide between two age groups in each country. In all countries under consideration, the group of millennials owns more smartphones than people of an older age. The inequality is largest in India and Uganda (3 times) and the smallest in South Korea (1.2 times) and in the U. S (1.4 times). To measure that inequality a special "factor" is proposed in the next section of this paper.

2.2. Digital inequality factor (DIF)

To assess inequalities of scale of digital divide related to different social, physical, demographic or other environmental parameters it is possible to use proportions of DDQ values. For that purpose the *digital inequality factor (DIF)* is proposed. It is intended to reflect level of inequality and is calculated as the proportion between DDQ's of respective entities (countries, organizations, groups etc) calculated for the same group (e.g. age group, gender, race etc). The international comparison of digital divides is expressed by DIF as follows:

$$DIF = DDQ_A / DDQ_B$$

where DDQ_A = digital divide quotient of country A; DDQ_B = digital divide quotient of country B.

With reference to comparison of the level of inequality of smartphone ownership (as a measure of interactive communication capability) across different age groups, it is possible to calculate values of DIF factors in respective countries. Examples of such a calculation are presented in Table 3.

Table 3. Digital inequality factor (DIF) by age groups: comparative extent of inequality for different countries relative to the U.S. (as a benchmark)
Smartphone ownership by % of age group population (2015). DIF calculated on basis of data extracted from: www.pewglobal.org . Note: DDQ values are the same as in Table 2.

Country	DDQ_A	DIF relative to the U.S.
U. S.	1.41	1.00
Japan	1.84	1.30
China	1.97	1.40
Germany	1.84	1.30
Russia	2.62	1.85
S. Korea	1.20	0.85
India	3.00	2.12
Ethiopia	n.d.	n.d.
Uganda	3.00	2.12
Malaysia	1.91	1.35

$DIF_A = DDQ_A/DDQ_{US}$

where DDQ_A = digital divide quotient in country A; and DDQ_{US} = digital divide quotient in the U. S.

It is easy to note in Table 3 that the largest extents of digital inequality (DIF) exist in India, Uganda (both DIF = 2.12) and Russia (DIF = 1.85). The lowest extent of digital inequality exists in South Korea (DIF = 0.85) that is less than in the U. S. by 15%. The DIF factor may be also used for assessment of digital inequality with regard to parameters other than the age of population group, such as gender, race, location (cities vs rural areas) etc, as well as for different elements of communication technology i.e. Internet penetration, Facebook penetration, WhatsApp penetration and others.

3. Conclusions and suggested further research

The proposed approach to measuring the digital divide in interactive communication has been developed in order to simplify assessment of that divide. Two new aggregate measures have been defined and explained. As shown in the examples, the proposed approach facilitates identification of extreme cases and approximate comparisons between any two subjects (countries, organizations, groups etc). These features are of particular importance in case of evaluation of communication technologies and systems. Digital divide in this domain may be of critical importance for assessment of conditions for trade negotiations, information flows and exchanges, financial operations, education etc. It should be added that the same set of two, relatively simple measures can be applied for assessment of gaps and delays in development of other kinds of technology.

Further research on such applications would require specific studies on selection of representative parameters and availability of statistical data. Even if the scope of application were limited to or focused on communication technologies and systems, there is a need for further research on the dynamics of the digital divide by studying DDQ and DIF as functions of time. It would require data time series for selected parameters and technologies. Such research could provide interesting insights into trends of the digital divide as an economic, social and cultural phenomenon and could facilitate assessment of its potential consequences for the future.

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The Human Hand and Technology Adoption

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Abstract

We examine the interactive effects of hand technique (one vs. two), screen-type, and screen size on behavioral intentions to adopt a technology device (i.e., smartphone). We find that these effects are mediated by three theorized adoption drivers: performance expectations, effort expectations, and hedonic appeal. Results indicate that the strength of the mediated effects of each predictor is conditional on the remaining predictors, thus illustrating the relevance of cue and context configurable models in the study of technology adoption. Managerial implications are derived.

1. Introduction

Mobile device technologies are evolving at an explosive pace whereas the human organism that interacts with these technologies is, essentially, an entity of fixed proportions. So great is the gulf that technologists have begun to explore ways to not only "hack" human perception and performance (e.g., virtual reality, bionics), but also to integrate technology with our biology (e.g., cortically controlled interfaces). While these advances can be transformative for certain populations such as medical patients, a recent survey by the Pew Research Center (Funk, Kennedy, & Sciupac, 2016) indicates that most persons are more concerned than excited by the prospects.

One reason users may be wary of futuristic technologies is that everyday experience with technologies often teaches that "more" turns out to be "less" (Eytam, Tractinsky, & Lowengart, 2017). Nowhere is this more visible than the case of smartphone devices. Consumers want larger screens to view more content and to feel more immersed, but they also want smaller screens for enhanced portability and controllability. Therefore, bigger screens may not always be better for everyone or for different contexts (e.g., texting, browsing, reading, or watching a video). Visionary Steve Jobs replied when asked why not make his phones bigger, "You can't get your hand around it. No one's going to buy that" (Edwards, 2014). One way designers have sought to increase screen size but not device size is by eliminating physical bezels. At the same time, some segments of consumers have adapted to larger device sizes by switching from a one-hand holding technique to a two-hand technique (Huang, Limke, & Kong, 2017).

In this research, we empirically examine these three factors with respect to consumers' technology adoption decisions for smartphone devices. Specifically, we consider the three-way interaction of (1) *screen-type* (no bezel vs. bezel), (2) *screen size* (small vs. large), and (3) *hand* technique (one vs. two) on consumers' intentions to adopt a smartphone device. Our theoretical framework integrates insights from literatures on technology adoption and acceptance (e.g., Brown & Venkatesh, 2005; Venkatesh et al., 2003; Venkatesh, Thong, & Xu, 2012), as well as human factors (e.g., Jeong & Liu, 2017).

2. Consumer technology adoption and its drivers

A firm's survival often depends on its ability to understand how consumers come to accept or adopt new technologies. This requires knowledge integration across processes of individual change (e.g., perception, learning), social phenomena (e.g., word-of-mouth), and technological innovation.

Early models of individual change include the Theory of Reasoned Action (Fishbein & Ajzen, 1975), Theory of Planned Behavior (Ajzen, 1991), and the Technology Acceptance Model (Davis, 1989). Subsequent researchers introduced newer notions of cognition (e.g., Thompson, Higgins, & Howell, 1991), motivation (e.g., Davis, Bagozzi, & Warshaw, 1992), social influence (e.g., Compeau & Higgins, 1995), and innovation diffusion (e.g., Moore & Benbasat, 1996). Venkatesh et al. (2003) reviewed and synthesized various adoption models into a unified theory of acceptance and use of (UTAUT) for organizational contexts. Venkatesh, Thong, & Xu, (2012) later updated this model for consumer contexts (UTAUT2).

A primary insight of UTAUT2 is that consumers' technology adoption decisions are well explained by a relatively small number of technology perceptions or drivers. This enables researchers to expose consumers to a given technology, measure key perceptions, and then predict behavioral intentions or behaviors related to technology adoption. Two of the key adoption drivers include *performance expectancy* (i.e., degree to which a technology is expected to deliver desired benefits) and *effort expectancy* (i.e., the degree to which the technology is expected to be easy to use).

We also examine *hedonic motivation* (i.e., pleasure derived from the technology). Whereas prior research focuses on hedonics in terms of how "fun" a technology is (e.g., Brown & Venkatesh, 2005), our focus is on the extent to which the technology provides pleasure by visual aesthetics. Prior research has linked visual aesthetics to related outcomes such as usability (Tractinsky, Katz, & Ikar, 2000).

Our empirical context is smartphone devices. In this context, manufacturers compete intensely on the attributes of *screen-type* (no bezel vs. bezel) and *screen size* (small vs. large), as these are key considerations for consumers (Kim & Sundar, 2014). Less understood is whether screen-type and screen size directly affect behavioral intentions to adopt or if their effects are mediated.

Further, whereas most technology adoption research examines on the effects of device features on user responses, we also consider the effects of a user-based "feature" – the *human hand*. Specifically, we focus on the consequences of one-hand versus two-hand grasping. This focus derives from relevant findings in the human factors literature. For example, Huang, Limke, & Kong (2017) find that tasks were completed faster with one-hand (vs. two-hand) interaction, but also with a higher error rate, especially when screens contained a denser layout. Similarly, Trudeau (2016) found that two-hands versus one-hand usage reduced task variability and afforded greater thumb coverage of larger screens.

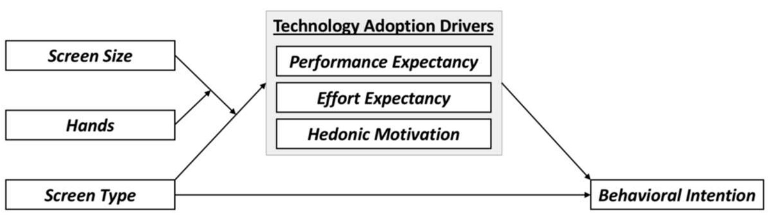

Figure 1. Theoretical framework

3. Methodology

We conducted an in-person experiment in which 113 current smartphone device users viewed one of four prototypes and responded to questions derived from the theoretical framework depicted in Figure 1. The resulting data was subjected to regression and mediation analyses with bootstrap estimation.

3.1. Participants

Participants were recruited using systematic random sampling at a cooperating supermarket and mall, both of which are located in a large and diverse metropolitan area of the southeastern United States.[1] All participants were qualified as currently owning a smartphone device. Their ages skewed young: 54.9% were 18-24 years old, 23.0% were 25-34 years old, 11.5% were 35-44, and 10.6% were 45 or older. The majority of participants reported that their highest level of educational attainment was a bachelors or graduate degree (62.8%) while a similar majority identified as males (66.4%).

3.2. Design, stimuli, and procedure

Each participant was randomly assigned to view a life-sized, grayscale depiction of a smartphone (see Figure 2) that featured one of two screen types (no bezel versus bezel) and one of two screen sizes (small versus large, operationalized as 4.7" versus 5.8"). In addition, participants were classified according to whether they primarily used a smartphone device with one hand or two hands. Thus, the experiment employed a 2 (screen type) × 2 (screen size) × 2 (hands) between-subjects design. The following instructions accompanied the presentation of the smartphone stimuli:

> *Imagine that you have entered an electronics store and you are considering the purchase of a new smartphone. You see the following phone. It is a* [screen-size]*,* [screen-type] *phone. For purposes of this scenario, imagine this phone is your favorite brand.*

To help "unbrand" the smartphone stimuli, the home button was given a shape that does not appear in the marketplace (sexagon), while other screen icons were shown as abstract, labelled shapes (square, circle, triangle, round rectangle, polygon). The smartphone stimuli remained viewable as participants responded to the study measures. After completing all measures, participants were debriefed.

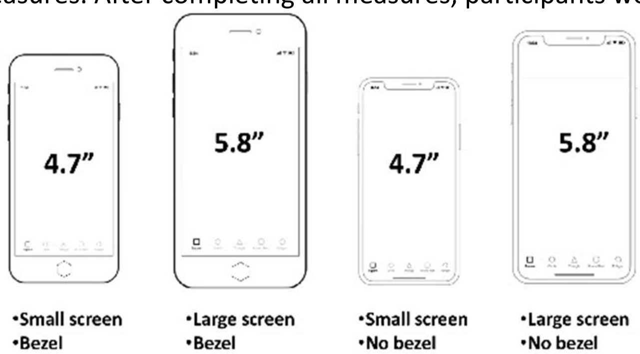

Figure 2. Smartphone stimuli

3.3. Measures

The three theorized technology adoption drivers as well as behavioral intentions to adopt were measured using seven-point scales. Performance expectancy was measured by using the stem "Given this scenario, I feel this phone will be ____" and the response anchors Ineffective/Effective and Inefficient to use/Efficient to use (α = .75). Effort expectancy used the same stem but the response anchors were Not easy to use/Easy to use and Uncomfortable to use/Comfortable to use (α = .90). Hedonic motivation used the stem "The design of this smart phone is ____" and the response anchors Not cutting edge/Cutting

[1] The authors thank Jiongtong Fang, Zhihong Liu, and Jiaming Yang for their assistance in administering the survey.

edge and Not innovative/Innovative (α = .88). Behavioral intentions to adopt were measured using three items, with the stem "Given the scenario, I feel ____ to purchase this phone" and the response anchors Unwilling/Willing, Not eager/Eager, and Not inclined/Inclined (α = .92, Guttman's split half = .84).

4. Results

We first checked the manipulations. For the screen-type manipulation, 81.4% of participants correctly identified whether the phone they saw had a bezel or not. This exceeds the random guessing rate of 50% ($z = 6.68$, $p < .01$). With respect to the screen size manipulation, participants responded to a seven-point item with the stem "The smart phone in this scenario had a _____" and the response options Small screen/Big screen. The mean was higher for participants in the large screen size than the small screen size condition ($M_{5.8''} = 5.47$ vs. $M_{4.7''} = 3.69$; $t(111) = 8.71$, $p < .001$). Thus, the manipulations were successful.

As our theoretical framework (Figure 1) indicates conditional mediation processes, the data were analyzed according to methods advocated by Hayes (2013). For exposition, we take screen-type as the focal exogenous variable whose impact on behavioral intentions is mediated by the theorized technology adoption drivers: performance expectations for the technology, the expected effort required to use the technology, and the hedonic appeal of the technology. We then ask whether the extent or nature of these mediation pathways varies according to the size of the screen involved. That is, are the perceptions regarding performance, effort, and hedonics equally relevant with regards to smaller versus larger screens? However, to stop here would be to ignore the point of contact between the user and the device (i.e., human hands). Thus, we also ask whether the mediated screen-type effects, which are moderated by screen size, are themselves changing at different rates based on hand usage (one vs. two).

Table 1. Effects of device and user factors on technology adoption drivers

	Performance Expectancy	Effort Expectancy	Hedonic Motivation
Screen-type	1.03*	1.09	1.29**
Screen size	–.19	–.35	.33
Hands	.75	.64	.85
Screen type × Screen size	–1.01	–1.02	–1.35*
Screen type × Hands	–.88	–1.02	–1.45*
Screen size × Hands	–1.12	–1.01	–.80
Screen type × Screen size × Hands	2.19*	2.45*	2.68**

*p < .05; **p < .01

We begin by examining the links between the exogenous factors (screen-type, screen size, hands) and the mediating variables (performance, effort, and hedonics). Here, we expect to observe significant three-way interactions in moderated regression analyses. This expectation is confirmed for performance expectancy (β = 2.19, p = .01), effort expectancy (β = 2.45, p =.02), and hedonic motivation (β = 2.68, p < .01). The R-square for these regressions was .21, .16, and .17, respectively. To facilitate interpretation, we provide a table of coefficients (Table 2) and plots of the interaction effects (Figure 3).

Comparison of cell means for one-hand smartphone users versus two-hand smartphone users revealed significant differences in the effects of screen-type and screen size on technology adoption drivers. One-hand users perceived smartphones with bezels (versus no bezels) as significantly less likely to perform well (p = .01) and significantly less hedonically appealing (p = .03) when screen size was small but not when it was large (p = .95 and p = .88, respectively). They perceived no significance difference in the likely ease of use for both small and large screen sizes (p = .10 and p = .89, respectively).

A reverse pattern emerged for two-hand users, who perceived no differences in smartphones with bezels (versus no bezels) with respect to performance expectancy (p = .78), likely ease of use (p = .90), or hedonic appeal (p = .66) when screen size was small. However, when screen size was large, smartphones with bezels (versus no bezels) were perceived as significantly less likely to perform well ($p < .01$), significantly less likely to be easy to use ($p = .01$), and significantly less hedonically appealing ($p = .02$).

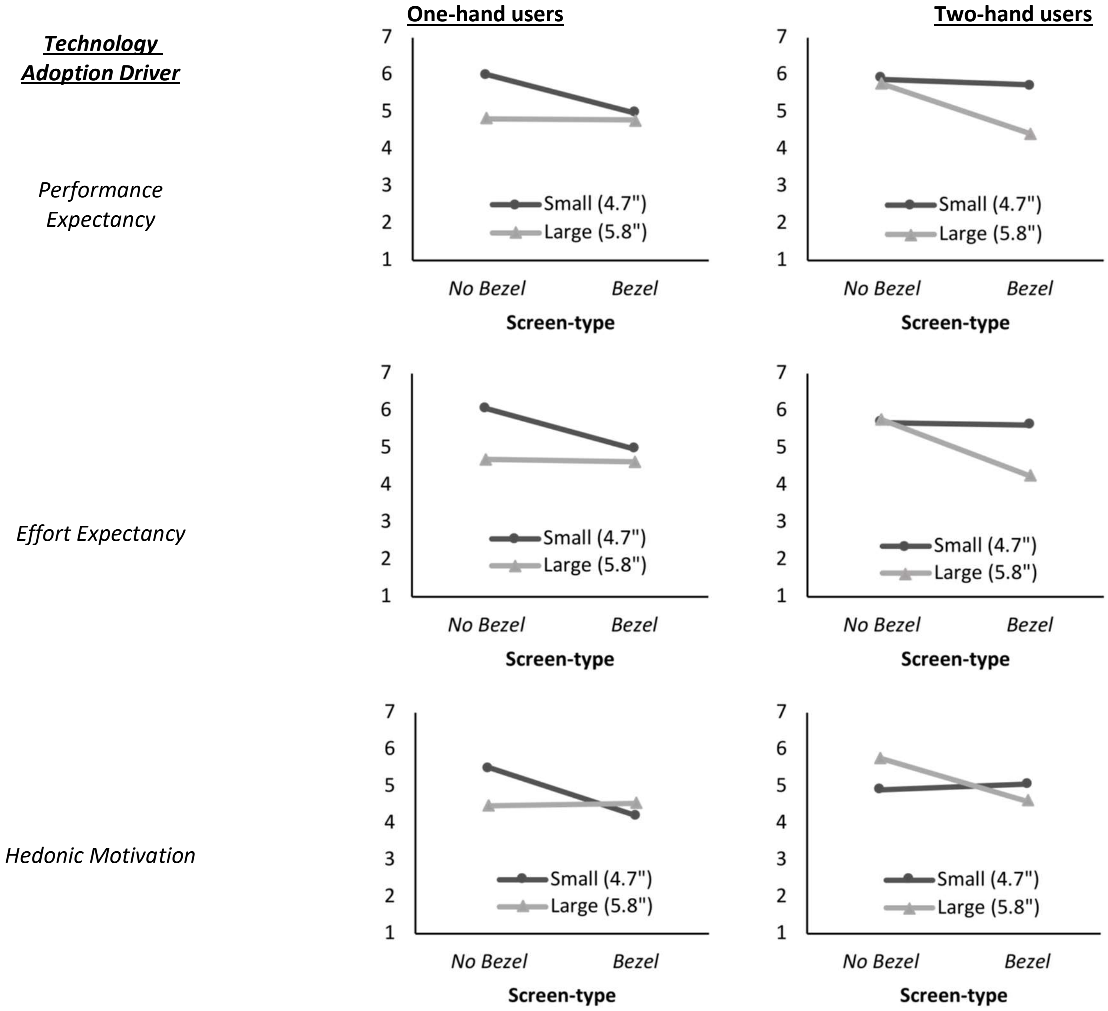

Figure 3. Effects of device and user factors on technology adoption drivers

Rather than assuming that the interaction effects of the predictors on the technology adoption drivers imply indirect effects on behavioral intentions, we explicitly test for such a process by examining the indices of conditional moderated mediation as well as the indices of moderated mediation. As shown in Table 2, the indirect effect of a smartphone device's screen-type on behavioral intentions depends on both its screen size as well as the number of hands used to hold the device.

For example, for one-hand users, performance expectancy is a significant mediator of the screen-type effect on behavioral intentions when screen size is small (effect = .45, $p < .05$) but not when it is large (effect = .01, $p > .05$. In contrast, for two-hand users, performance expectancy is not a significant mediator of the screen-type effect on behavioral intentions when screen size is small (effect = .06, $p > .05$) but is a significant mediator when screen size is large (effect = .58, $p < .05$.) Further, the difference in these differences in mediation across one-hand and two-hand is significant (effect = .96, $p < .05$).

Table 2. Indirect effects of device and user factors on behavioral intentions

Technology Adoption Driver	Hands	Screen size: small (4.7")	Screen size: large (5.8")	Δ Mediation[a]	Δ (Δ Mediation)[b]
Performance	*One*	.45*	.01	.01 – .45 = –.44	
	Two	.06	.58*	.58 – .06 = .52	.52 – (–.44) = .96*
Effort	*One*	.32	.02	.02 – .32 = –.30	
	Two	.02	.44*	.44 – .02 = .42	.42 – (–.30) = .72*
Hedonic	*One*	.29*	–.01	–.01 – .29 = –.30	
	Two	-.04	.26*	.26 – (–.04) = .30	.30 – (–.30) = .60*

*$p < .05$

[a]Indices of conditional moderated mediation; [b]Indices of moderated mediation

5. Discussion

Results support the hypothesized direct and indirect effect of the focal exogenous variable (screen-type) on behavioral intentions of consumers. This indirect effect was mediated by the adoption drivers: performance expectancy, effort expectancy and hedonic motivation. In turn, the exogenous factors (screen-type, screen size, hands) exhibited a significant three-way interaction with the mediating variables (performance, effort, hedonics), revealing an important, configurable relationship between the exogenous variables and the adoption drivers.

Consequently, when accounting for *hands* (one-hand smartphone users versus two-hand smartphone users) results revealed that one-hand users perceived smartphones with bezels (versus no bezels) as significantly less likely to perform well and significantly less hedonically appealing when screen size was small, but not when it was large. Yet, they perceived no significant difference in the likely ease of use for both small and large screen sizes. However, an opposite pattern was observed for two-hand users. More specifically, one-hand users' performance expectancy mediates the effect of screen-type on behavioral intentions when screen size is small but not when it is large, while two-hand users' performance expectancy mediates only when the screen is small, not when it is large (these differences in mediation across one-hand and two-hand are significant).

6. Limitations and Future Research

Experimental designs allow for enhanced control over variables of interest in a proposed causal chain. However, this control can come at a cost. A chief limitation of the current study is that participants were not able to hold the smartphone device stimuli and that the stimulus designs included elements not present on existing devices (e.g., sexagonal buttons). Though this limitation is somewhat mitigated by the fact that all participants were current smartphone device users and could reference personal experience, it is possible that certain perceptions of devices only emerge or attain importance while in the midst of physical contact. Future research may address this limitation by creating or simulating physical experiences with devices. Similarly, future research may include contextual stimuli, since hedonic perceptions of designs may be driven by initial or early experiences (Niedrich & Swain, 2003), recently experienced designs, or notions of an "ideal" design (Brunel & Swain, 2007).

A second limitation of this research is that the relatively small sample precluded examination of additional moderators of technology perceptions such as demographics (Venkatesh, Thong, & Xu, 2012). For example, studies of human hand anthropometry confirm that males generally have larger and biomechanically distinct hands compared to females (Pereira, et al., 2013; Ruiz et al., 2006). Similar distinctions have been observed across other population variables such as occupation and ethnicity (Garrett, 1971). Such differences may have a systematic impact on the perception and interaction styles selected for handheld devices. One potentially fruitful and related direction for future research would involve linking hand anthropometry to perceptions of device controllability and intimate knowledge, which may enhance feelings of psychological ownership (Kirk, Swain, & Gaskin, 2015). A related consideration is the potential disconnect that can exist between short-term and long-term drivers of technology adoption. For example, when making adoption decisions, consumers often fail to anticipate the effects of extended technology use on outcomes such as posture (Kietrys et al., 2015), attention (Riek et al., 2003), reasoning (Sanchez & Branaghan, 2011), and comprehension (Ebtisam et al., 2016).

Relatively few studies have considered the more general question of product size and whether or when consumers perceive size differences. Krider, Raghubir, & Krishna (2001) show that when comparing the area covered by different shapes, consumers tend to make an initial comparison based on a single, linear dimension and that this single dimension maintains greater salience over the secondary dimension. As a result, single dimensions tend to dominate two-dimensional estimations. Carlson, Weathers, & Swain (2016) find that consumers react differently to manufacturer's claims of product enlargement depending on prior knowledge of the original size and whether the enlargement is framed as a "bonus" or not. Similarly, consumers interpret changes in quantity differently depending on whether the change is expressed in absolute or relative terms (Weathers, Swain, & Carlson, 2012).

In conclusion, *screen type*, *screen size,* and *hands* are important exogenous variables to consider when developing technology for consumers. This suggests that developers, designers, and marketers of technology products for consumers should consider segmenting according to screen-to-body size (Lee et. al 2018), continue to create software that adjusts screen size to facilitate use (e.g., enable One-Handed Mode on Galaxy S9 or iPhone 10), and develop marketing communications that could encourage consumers to use their product with hand techniques that better fits with the product offered (e.g., Galaxy's SV advertisement, which asks, "Why use one hand when you could use two?").

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Effect of machining parameters on the uncut fibers of a unidirectional flax fiber reinforced composite

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Abstract

In recent years, flax fiber-reinforced polymers (FFRP) are being widely used due to their inherent properties comparable to those of glass fiber reinforced polymers (GFRP). They are partially biodegradable and light weight with good intrinsic modulus and strength. However, milling these composites introduces defects like a poor surface quality with a lot of uncut fibers. The main objective of this study is to analyze the effect of machining parameters and fiber orientation on the uncut fibers (characterized by the number and length of the uncut fibers) of unidirectional FFRP. A full Split-Split Plot Block design of experiment approach was conducted for the analysis. It is shown that the uncut fibers extent depends significantly on the feed rate, the fiber orientation and the cutting tool geometry. The cutting speed does not influence the quantity of uncut fibers. A low feed rate (0.05 mm/rev) and a cutting tool geometry which enhances the fibers shear with a zero-helix angle are shown to minimize the delamination during the up-milling process of unidirectional flax/epoxy composite.

1. Introduction

Thanks to their high intrinsic modulus and strength which are comparable to those of glass fiber-reinforced composites (GFRP) (Do Thi, 2011; Shah et al., 2013), their biodegradability, their low weight and low cost (Bogoeva-Gaceva et al., 2007), flax fiber-reinforced plastics (FFRP) are increasingly attracting the interest of all fields (Avril et al., 2012). Furthermore, they have been considered by several researchers and industrials as a substitute for GFRPs since flax fibers have an intrinsic strength similar to glass fibers in addition to a better fatigue strength (Liang et al., 2011; Liang et al., 2012) and lesser abrasiveness towards cutting tools. Thus, they provide a longer tool life which represents a great economic benefit for companies (Bouzouita, 2011).

However, the viscoelastic nature of natural fiber-reinforced plastics (NFRP) generates a poor surface quality when trimming them. A lot of uncut fibers appear during the process which leads to a high delamination factor (Fd). The latter represents the ratio between the nominal dimensions of the cut and the maximum dimensions obtained after cutting. Babu et al. (2013) investigated the machinability of three different unidirectional NFRPs namely banana/polyester (BFRP), hemp/polyester (HFRP) and jute/polyester (JFRP) composites. They highlighted that delamination increases with the feed rate and decreases with the cutting speed. Therefore, cutting at a low feed rate and a high cutting speed improves the surface finish and minimizes the delamination. Azmi et al. (2016) found that the feed rate is the most influencing factor on the surface roughness in milling kenaf fiber reinforced plastic composites. They showed that the cutting speed has no effect on the surface finish quality. In the milling of GFRPs, the feed rate was found to be the most influencing cutting parameter on the delamination followed by the cutting speed (Jenarthanan et al., 2013). Those contradictions in terms of the effect of the cutting speed on the surface finish quality were explained by Chegdani et al. (2015) research who studied the influence of natural fiber types on the tribological behavior during the milling process. They concluded that the natural fiber shearing mechanism depends strongly on the fiber type. Recently, Delahaigue et al. (2017) showed that the fiber orientation greatly influences Fd. In fact, the best surface finish is obtained when the fibers are oriented at 0° and the worst for fibers at -45°. Further, the authors advise against the down-milling mode which produces a poor surface finish.

The delamination factor Fd often characterized the delamination (Davim & Reis, 2003; Erkan et al., 2013; Sreenivasulu, 2013). However, these «one-dimensional» evaluation criteria cannot evaluate the extent of the defect. A two-dimensional evaluation criterion (2D) is then necessary to properly characterize the extent of the delamination. Thus, Wang et al. (2017) proposed a novel approach to evaluate the uncut fibers extent after edge trimming of carbon-fiber-reinforced composites based on an areal factor (Ad) (the ratio between the nominal area of the cut and the actual area after cutting including the size of uncut fibers).

No previous work has been carried out on optimizing flax fiber composites delamination. This paper aims to investigate the influence of the cutting parameters like the feed rate and cutting speed (f and Vc), the fiber orientation (θ) and the cutting tool geometry on the delamination extent. As recommended by Bradley & Nachtsheim (2009) who argued that the split-plot design of experiment (DOE) are more efficient than completely randomized designs and superior in terms of cost and validity. Dry up-milling experiments were conducted with a full Split-Split Plot Block DOE approach.

2. Methodology and experimental procedure

2.1. Material

The material used during this study consists of an unidirectional 15-ply flax fiber impregnated with epoxy resin. The laminated plates were made using 15 unidirectional long flax fiber plies. They were molded by the vacuum assisted resin transfer molding (VARTM) method to a fiber volume fraction (Vf) of 41.1%. The total thickness of each plate is about 4.597 mm (corresponding to the mold cavity thickness).

The flax plies were first dried in an oven at 80°C for 8 hours in order to reduce their moisture content. The pressure of the resin injection was gradually adjusted to maintain a constant injection rate and a complete impregnation. After the impregnation, the resin was cured in a hot-platen press at 80°C for 3 hours. Figure 1 shows the VARTM setup (the press and the mold installed inside the press on the right and the pressure pot on the left). A total of 4 [0_{15}] composite plates have been molded for the machining experiments. A typical plaque is shown in Figure 2.

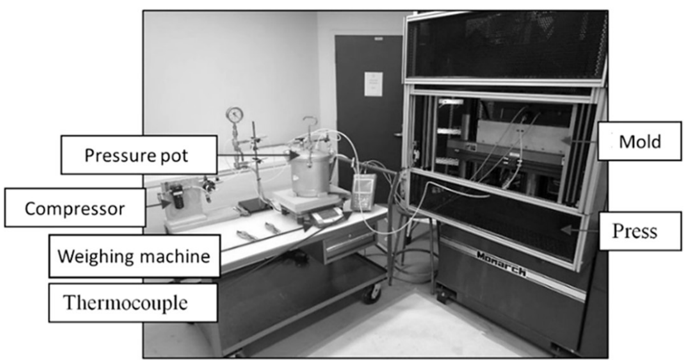

Figure 1. VARTM setup

2.2. Experiment factors

A three-axis numerically controlled machining center, HURON K2X10 (figure 2) was used for the machining operations. To optimize the surface finish quality, the influence of cutting parameters namely cutting speed (Vc), feed rate (f), fiber orientation (θ) and cutting tool geometry on the extent of the delamination was investigated. These parameters were identified in the literature as the most significant for the milling of fiber reinforced composites. A total of three Vc values, six f values, four fiber orientations and two different cutting tools (table 1) were considered in the plan of experiments. Figure 3 defines the convention of fiber orientation while table 1 shows the factor levels of the study.

Tool #1 was a two-flute polycrystalline diamond end mill (PCD) (figure 4.a), as used by Bérubé (2012), while tool #2 was a two-flute uncoated carbide end mill with 70° cutting profiles (figure 4.b). From one flute to the next, tool #2 cutting profiles were inverted to enhance fiber shearing which reduces the risk of delamination. The cutting tools specifications are shown in table 2.

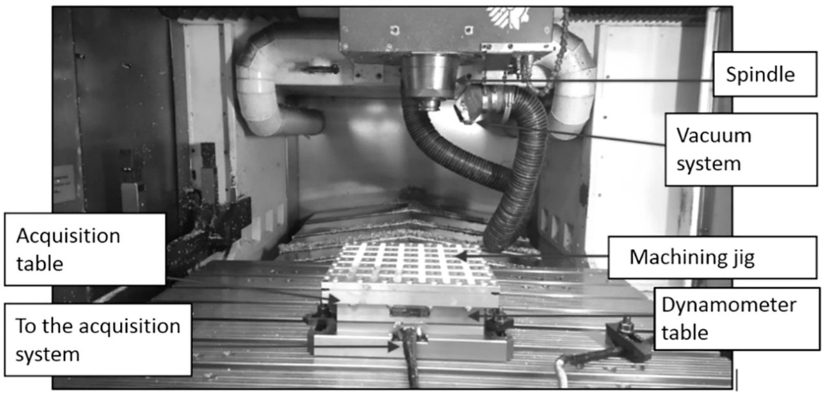

Figure 2. Milling setup

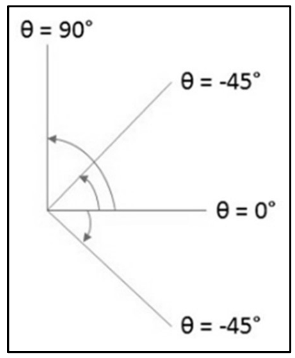

Figure 3. Fiber orientation definition

Table 1. Experimental factor levels

Factors	Factor levels					
Cutting tool	Tool #2	Tool #1				
Cutting angle θ (°)	-45	0	45	90		
Cutting speed Vc (m/min)	200	400	600			
Feed rate f (mm/rev)	0.025	0.050	0.100	0.200	0.300	0.450

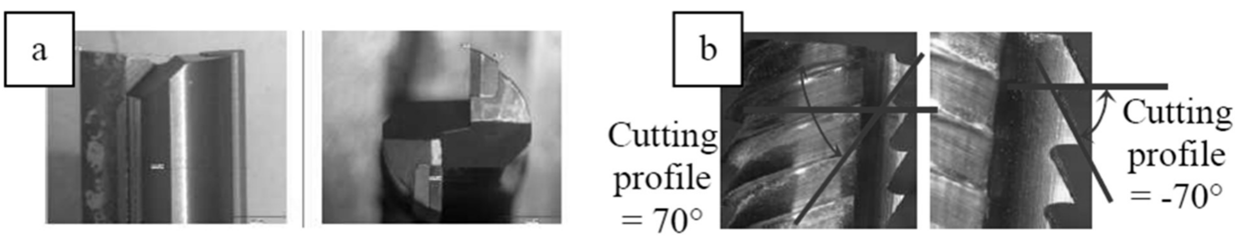

Figure 4. Cutting tools: a) tool#1 and b) tool#2 (Karabibene et al., 2017)

Table 2. Cutting tools specifications

Tool	Diameter	Flutes number	Cutting edge radius	Helix	Coating
#1	9.525 mm	2	5 µm	0°	Diamond PCD
#2	9.525 mm	2	4 µm	0°	Uncoated

The factors levels were chosen following the conclusions of Delahaigue et al. (2017) and based on the technical datasheets of the tools. In fact, Delahaigue et al. (2017) concluded that to minimize cutting forces and roughness when trimming unidirectional flax/epoxy composite, the feed rate should be medium and the cutting speed should be high. They have also defined limits in which Ra and cutting forces remain acceptable. Moreover, preliminary tests were performed to validate and refine the factor levels.

The composite plaques were hold to the machining setup using screws (figure 5) to minimize the vibration effect on the surface finish quality. Therefore, machining vibration effects were neglected in this analysis. Further, the cutting tool was regularly inspected, i.e., after each 7 cutting combinations, to control its wear. A new unaffected area of the cutting tool was systematically selected after every 72 tests (which corresponds to a cutting length of 2.64 m). Consequently, the tool wear effect was also neglected. Thus, dry up-milling tests were carried out.

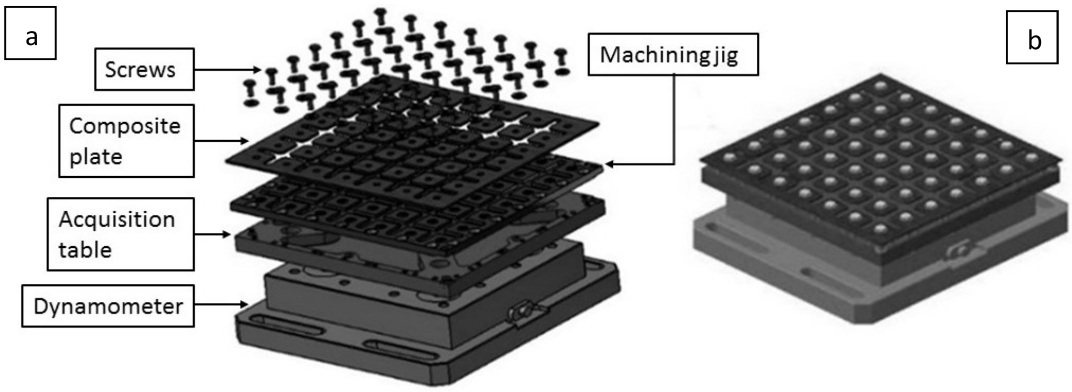

Figure 5. Plates fixation: a) exploded view and b) assembled jig

2.3. Trimming process and design of experiment

A Split-Split Plot randomized complete block design (SSPRCPD) was selected for the present experiment. It allows the minimization of the response variability and reduces the experimental errors. The design was replicated twice for a total of 288 machining combinations ($6\,f\ \times 4\,\theta\ \times 3\,Vc\ \times 2\ tools\ \ \times 2\ replications$).

2.4. Delamination extent measurement

The delamination was investigated based on Wang et al. (2017) research. They investigated a two-dimensional evaluation approach to characterize the delamination extent (Ad). A MATLAB program, inspired by Wang's was developed for this purpose. Firstly, the coupons obtained after milling were cleaned with compressed air. They were then photographed using a 23 MP resolution camera. The MATLAB processing sequence is organized as follows (figure 6):

- Convert the true color image (figure 6.a) to grayscale intensity image (figure 6.b);
- Select manually the area of interest, i.e. the cutting-induced delamination area, to reduce the computational time (figure 6.c) and extract this area (figure 6.d);
- Binarize the selected area using an Otsu's method combined with the Heaviside step function (a discontinuous function equal to 0 for strictly negative real numbers resulted from the Otsu

segmentation and to 1 for all other values);
- Sum up the black pixels corresponding to uncut fibers. The extent of the affected region is calculated by multiplying the number of pixels by the size of the pixel.

Black pixels that do not correspond to delamination were considered as measurement error and were overwhelmed by the confidence intervals of the delamination measurements.

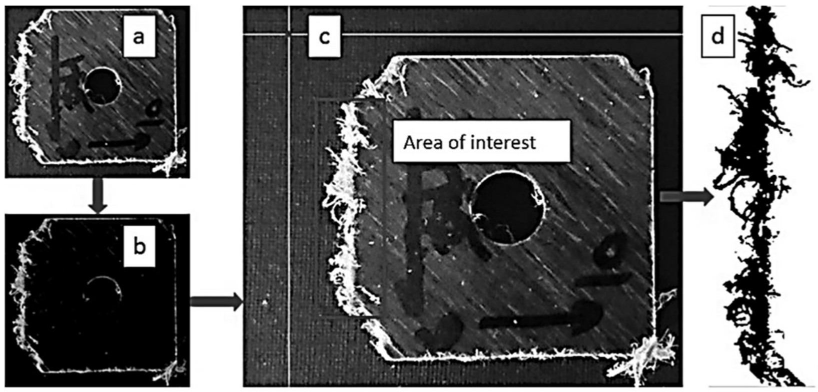

Figure 6. Delamination extent measurement steps

3. Experimental result

The delamination of the upper plie of the composite plates was obtained on samples machined following the up-milling mode. The areal delamination factor (Ad) was taken as the process response. Figure 7a shows the effect of the feed rate on Ad, regardless of the other factors (Vc, θ and the cutting tool). The feed rate has a significant influence on the delamination extent. The latter decreases when f increases from 0.025 to 0.100 mm/rev and then stabilizes when f increases from 0.1 to 0.45 mm/rev (confidence intervals overlap). The worst case (worst surface finish quality) was obtained for a low feed rate. When looking at the main effect on Ad of the cutting speed (figure 7b), the latter does not seem to be significantly influencing. The latter conclusion contrasts with the one in Jonarthanan et al. (2013) and in Babu et al. (2013). This could be explained by the nature of the fibers (Chedgani et al., 2015) and by the experimental factors levels. In fact, Jonarthanan et al. (2013) studied the milling of GFRPs. Flax fibers have a viscoelastic behavior while glass fibers are fragile. Their cutting mechanisms are different. The cutting speed in Babu et al. (2013) study had been selected in the range of 16 to 32 m/min which is much lower compared to the Vc level of this study. The contact time between the cutting edge and the fibers is much longer, the effect of the cutting speed is then more significant.

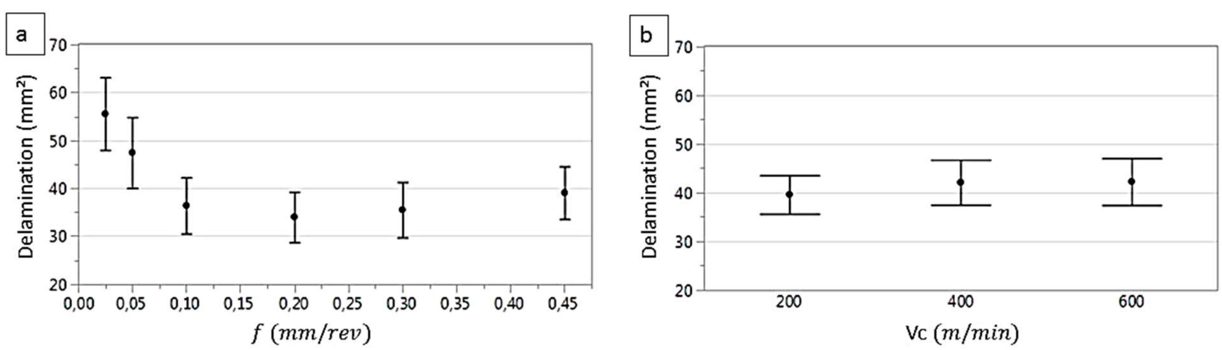

Figure 7. Evolution of the delamination extent with a) f and b) Vc (main effect, regardless the other parameters)

The evolution of Ad with the type of cutting tool and the fiber orientation is shown in figure 8. Tool #2 generates far lower damages on surface integrity (lower delamination). The uncut fibers size and quantity are lesser when using tool #2 whatever the fiber orientation. This can be explained by its special geometry which enhances the shear of fibers in the composites. Moreover, its low value of cutting edge radius (4 µm, lower than that of tool #1) facilitates the cutting of fibers. The worst surface integrity is obtained for fibers at -45° regardless of the tool used while the best surface quality occurs with a fiber orientation of 0°. The finish of the samples reinforced with fibers at 45° is shown to be better than that of samples with fibers at 90°. The fiber cutting mode causes this phenomenon. In fact, at -45° and 90°, the fibers are compressed under the contact tool/laminate, they bend instead of being cut by shear. Figure 9 compares the delamination in terms of uncut fibers quantity for coupons with fibers at 0° and -45° machined with both tool #1 and tool #2, considering a feed of $0.05\ mm/rev$ and a cutting speed of $200\ m/min$.

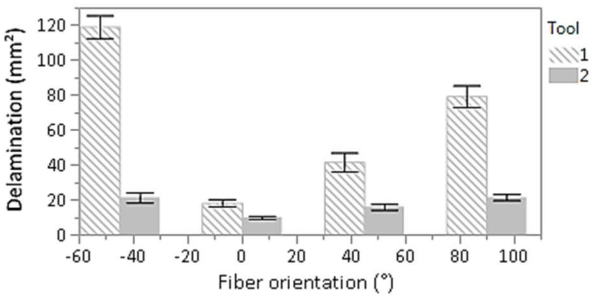

Figure 8. Evolution of the delamination extent with θ and the cutting tool

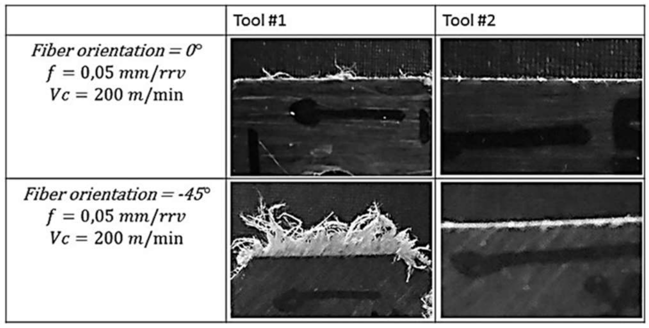

Figure 9. Comparison of delamination extent for particular cutting conditions

If we analyze the effect of the interaction between the fiber orientation and the feed rate regardless of the cutting speed and the cutting tool type (figure 10), the delamination behavior differs depending on f and θ. When the feed is minimum ($0.025\ mm/rev$), the worst delamination is generated when the fibers are oriented at $\pm 45°$ and 90° while the best surface finish is obtained at 0° fiber orientation. For the $f2$ feed rate ($0.05\ mm/rev$), the coupons with fibers oriented at -45° and 90° produce an equivalent delamination. Once again, the lowest delamination level is obtained when the fibers are oriented at 0°. The 45° orientation generates medium delamination for this feed rate. For $f3$ ($0.1\ mm/rev$) and $f4$ ($0.2\ mm/rev$), all different ply angles θ produce significantly different delamination levels. For samples milled at $0.3\ mm/rev$, the delamination of surfaces with fibers at 45° and 90° are similar. When the feed is maximum ($0.45\ mm/rev$), the 0° and 45° fiber orientation are equivalent. It is interesting to note that regardless of the feed rate, the samples with fibers at -45° undergo an almost constant Ad (confidence intervals overlap). To summarize, whatever the feed rate, the worst delamination is obtained for a fiber orientation of -45° while the lowest delamination is obtained for a θ of 0°. For fibers oriented at -45 °, the feed has no influence on Ad and the results are very dispersed (large confidence intervals). As for the other angles, Ad decreases when f increases from $f1$ to $f3$ and then stabilizes. Cutting with tool #2 is cleaner and sharper. Therefore, the best surface finish is obtained for fibers at 0°, a $0.1\ mm/rev$ feed rate and tool #2.

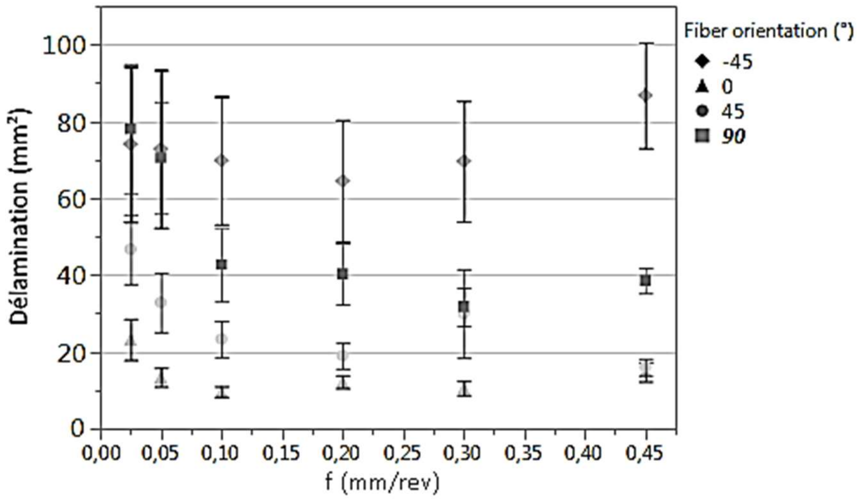

Figure 10. Evolution of the delamination extent with f and θ

The Pareto chart of Ad is represented in table 3. Only significant factors are represented. The feed rate is shown to have the greatest influence on the uncut fibers extent The cutting tool seems also to be significant with respect to Ad even though its effect may remain low (high P-value compared to that of the feed rate). However, its influence strongly depends on the feed rate level, i.e. the interaction between the cutting tool and the feed rate comes second. The fiber orientation, its interaction with the cutting tool and with f also affect delamination (table 3).

Table 3. Pareto chart of the delamination analysis

Factors		P-value
f (mm/rev)		0.00000
Tool × f (mm/rev)		0.00000
Tool × Fiber orientation (°)		0.00001
Fiber orientation (°)		0.00120
Fiber orientation (°) × f (mm/rev)		0.00496
Tool		0.00665

The Pearson-correlation coefficient (R^2) was found to be equal to 80.2%. The variation of the factors considered as influential explains the 80.2% of the variation of Ad. This coefficient is not sufficient to validate the model (the standard of significance is 85%). This can be explained by the locally non-homogeneous mechanical properties of the machined plaques because of non-similar fibers distribution in the matrix. The intrinsic error of the imaging measurement method could also explain this low coefficient. Nevertheless, the degree of liberty (DDL) of the model error is very high (246 DDL excluding the outliers) compared to the model DDL (6 DDL corresponding to the number of the model factors). In addition, the mean square error (MSE) is small compared to the mean delamination value (the MSE represents 10% of the delamination average). Finally, the Watson-Durbin coefficient (this coefficient detects the presence of autocorrelation in the residuals i.e. the presence of noise factor) is 1.92 ($\approx$ 2 i.e. the significance level) which validates that the model residual is not auto-correlated (absence of noise factor). These criteria validate the delamination prediction model below within the limits of the experimental work.

$$\mathrm{Ad} = \begin{cases} 94.603 - 0.039 \times \theta - 33.072 \times f - 50.157 \times Tool \quad (f - 0.1875) - \\ \quad 0.838 \times (\theta - 22.5) \times (f - 0.1875) - 0.078 \times Tool \quad (\theta - 22.5) & \text{For tool\#1} \\ \\ 21.733 - 0.039 \times \theta - 33.072 \times f - 50.157 \times Tool \quad (f - 0.1875) - \\ \quad 0.838 \times (\theta - 22.5) \times (f - 0.1875) - 0.078 \times Too \quad (\theta - 22.5) & \text{For tool\#2} \end{cases}$$

Here θ is in degree, f in mm/rev, Vc in m/min.

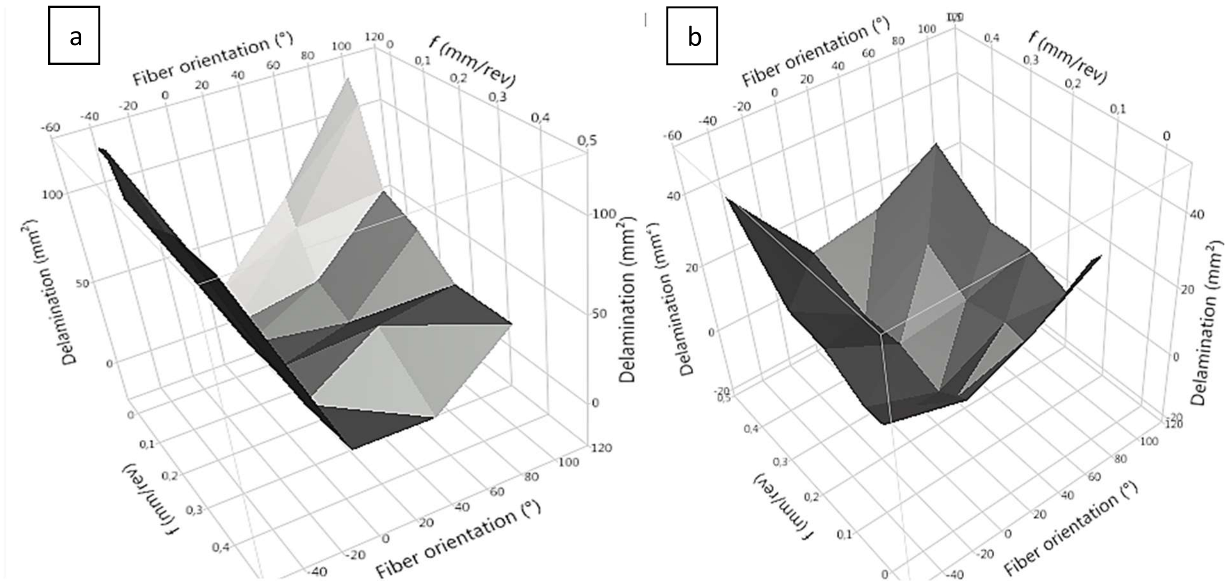

Figure 11. Response surface of the evolution of Ad with f and θ for a) tool #1 and b) tool #2

Figure 11 shows the surface response of the Ad evolution with f and θ depending on the tool. These results are consistent with the previous ones. For both tool #1 and #2, the lowest uncut fibers size is obtained with fibers oriented at 0° whatever the feed rate level. The delamination extent increases with the feed rate. Tool #1 generates more uncut fibers. Thus, the delamination extent depends on both f and θ and on their interaction.

Figure 12 summarizes the factors level which minimize the delamination (factors in abscissa in the figure). Globally, a fiber orientation of 0° and a low feed rate of 0.05 mm/rev provide the best surface finish. Better surface finish was obtained with tool #2 thanks to its geometry which enhances the fibers shear in the FRPs. A high cutting speed is recommended to maximize the material removal rate and thus the productivity (Vc has no influence on Ad).

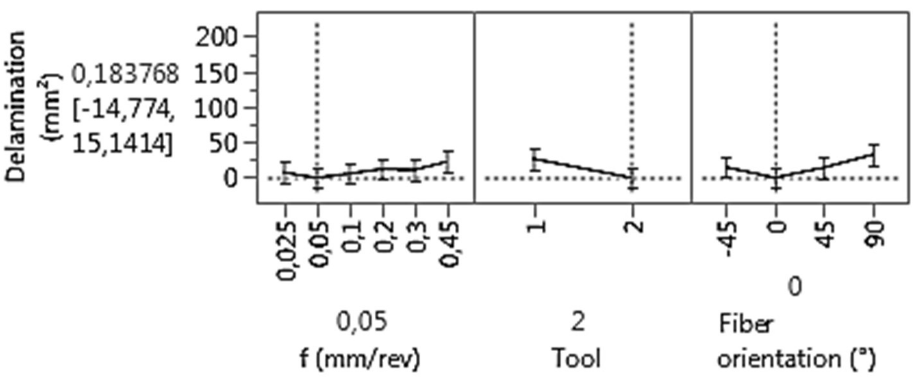

Figure 12. Main effects diagram and optimum cutting condition

To conclude, these results are consistent with the literature since on one hand the feed rate is the most influencing factor on the uncut fibers size. The latter increases with the feed rate and is minimum when the fibers are oriented at 0° which supports the results in Babu et al. (2013), in Azmi et al. (2016) and in Delahaigue et al. (2017). On the other hand, the cutting speed has no significant effect on Ad which supports the results of Azmi et al. (2016). This is in contrast with the results in Babu et al. (2013) that emphasize the importance of the cutting speed on Ad.

4. Conclusion

This paper aims to characterize the effect of machining parameters and fiber orientation on the delamination extent of unidirectional flax fiber-reinforced epoxy resin. It was shown that:

- The studied factors i.e. feed rate, fiber orientation and cutting tool geometry were well correlated with the areal delamination factor Ad.
- The feed rate was the most influential factor on the delamination extent while the cutting speed had no influence on it.
- The lowest quantity and size of the uncut fibers was obtained with fiber oriented at 0° with respect to the cut direction while the highest was generated when fibers are oriented at -45°.
- Tool #2 showed a better performance than tool #1 due to its special geometry which enhances the fibers shear.
- Depending on the factors level and their interactions when trimming, the delamination behaves differently

To reduce the length and quantity of uncut fibers, a low feed rate (0.05 mm/rev) and a carbide tool with a zero-helix angle and a low cutting-edge radius are recommended. This cutting combination leads also to the minimization of the cutting forces and the surface roughness (Karabibene et al., 2017).

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A Pilot Implementation of the Drum-Buffer-Rope and Reported Benefits

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Abstract

Today's market is competitive, and companies are forced to improve their response capabilities to stay ahead of the competition. Despite the reported benefits of the single unit flow and pull production, many companies are still utilizing a push production control system called manufacturing resource planning (MRPII). However, recent studies indicate that the drum-buffer-rope (DBR), a pull-push mixed production control approach, outperforms traditional MRPII in throughput, inventory, and cycle time. These are decisive factors in achieving rapid response capabilities. This paper represents a case study performed on a set of parts that were transformed from a pure MRPII production control approach to the MRPII-DBR mixed approach. The results indicate that utilizing DBR concepts in an existing MRPII system resulted in significant improvement in response capabilities.

1. Introduction

Currently, many companies utilize manufacturing resource planning (MRPII) systems to support their push production approach (Koh & Bulfin, 2004). Material requirements planning (MRP) was a prior development to MRPII. It was developed in the 1970's to help manufacturing companies better manage procurement of raw material based on master production schedules (Rashid, Hossain, & Patrick, 2002). It was by the 1980's that MRPII was introduced. MRPII is aimed at optimizing manufacturing processes by synchronizing work-in-process (WIP) with production requirements. MRPII adds to MRP by managing internal processes along with the management of raw material. This internal process management consists of in-plant scheduling and production controls, which include production planning, machine capacity scheduling, demand forecasting, and quality tracking. It has been widely accepted and implemented in an assortment of shops (Steele, Philipoom, Malhotra, & Fry, 2005). As early as the 1980's it was estimated that tens of thousands of firms were using MRPII systems (Rondeau & Litteral, 2001). In its traditional form, MRPII's foundation is formed by the push approach, the oldest of scheduling approaches (Needy & Bidanda, 2004). Using this approach, a product is pushed from steps upstream in the process to those downstream. With MRPII, orders are released based on lead times and a master schedule. Priority of in-process work is determined by lead time back off dates from the master schedule to the current operation. This concept has helped companies for decades manage in-process requirements and resource capacity based on a master schedule and lead times.

Yet, Needy and Bidanda (2004) explained how firms have shifted from the push MRPII systems to pull systems motivated by just-in-time (JIT) concepts. The shift from MRPII to JIT was an attempt to reduce inventory levels and subsequently production costs. It has gained wide acceptance throughout the industry. With the JIT approach, downstream processes signal processes upstream when to produce to fulfill demand. A commonly used signaling method is the Kanban. Yet, Kanban is not applicable to many production environments. Spearman, Woodruff, & Hopp (1990) pointed out that this is the reason why many of the older and less effective MRPII approaches remain today.

Constant WIP (CONWIP) is a pull-push production control logic that shares the same benefits of Kanban and can be applied to a wider variety of production environments. Advocates of the theory of constraints (TOC) have proposed what is known today as the drum-buffer-rope (DBR) methodology. This is similar to the CONWIP approach but is more general and can be readily utilized in pure job-shop environments. DBR is a pull-push scheduling approach that synchronizes all resources to the pace of the constraint, protected by a time buffer, and releases orders based on the constraint's consumption. It is a new production control methodology that appears to be gaining increased attention due to its impact on rapid response. The following section represents a review of the literature pertaining to the evolution of MRPII and DBR methodologies and their performance with respect to response capabilities. A case study is represented in Section 3 and concluding remarks are represented in Section 4.

2. Literature review

As previously stated, MRPII systems have been widely used and accepted by a variety of shops. As of 2004, results of full-scale applications of DBR was sparse and incomplete (Steele et al., 2005). However, reports on the early applications were reported by Steele et al. (2005) as, "encouraging, even compelling." Nanfang et al. (2008) stated that there is evidence from early applications that suggest DBR, a pull-push combination approach, can significantly increase throughput (TP) while decreasing inventory and cycle time (CT) compared to MRPII. In fact, the same source further stated that rigorous academic test has validated those early findings. In fact, current research has provided new positive results from DBR implementations. Xu, Ru, & Lui, (2010) concluded that DBR outperforms MRPII in CT and overall TP. In their case studies, due-date-performance increased significantly while CT significantly decreased as compared to MRPII. Another study, performed by Steele et al. (2005), showed that the performance of DBR is clearly superior to traditional MRPII implementations. In studies based on simulated systems, Koh & Bulfin (2004) showed that DBR outperformed MRPII.

Beyond simulated analysis, many companies have transformed from MRPII production approaches to DBR and have shared their results. In an actual implementation of DBR, due date performance (DDP) at a plant stayed level at 99.9% while inventory turns went from 17 to 32 (Steele et al., 2005). In another company, TP increased by 47% while inventory decreased by 50% and CT decreased by 40% (Klusewitz & Rerick, 1996). These are significant results that have allowed for these companies to respond more rapidly to the market.

In another study by Walker (2002) a company reported great results from using DBR. When the company was utilizing the MRPII system, the lead time was three-to-five weeks while their customers expected to have their product within two weeks of ordering. Once again, the application of DBR allowed the company to increase their customer delivery performance and rapid response ability thus gaining market share. As a result, they were able to drop the lead time down to a consistent 10 days for all of their products, a 52% to 71% reduction.

Xu et al. (2010) explained how MRPII does not consider the system's bottleneck. As a result, it fails to plan production requirements based on the bottleneck's capacity. This eventually leads to overloading the bottleneck and thus creating significant delays. In the end, DDP suffers and customer satisfaction is affected. They further stated how this poor DDP could increase inventory, as distributors are likely to try to protect themselves against the unreliable delivery performance with high stock levels. Also, because of its push approach, MRPII can build excessive and unneeded inventory "when delays in re-planning of the schedule occur resulting from changes in production requirements" (Needy & Bidanda, 2004). Excessive WIP will also likely build up as bottlenecks are overloaded and not able to produce their share of the workload. As a result, MRPII has poor DDP while encompassing high inventory and long CT.

Klusewitz & Rerick (1996) stated that DBR is "an on-going improvement process that specifically focuses on management decisions aimed at increasing throughput and controlling inventory levels for the organization." Steele et al. (2005) described DBR as a system that schedules the constraint (bottleneck) carefully while scheduling all other non-constraint operations casually. They described DBR as a three-step technique. In step 1, a schedule is developed by the constraint in such a way that it is optimized, thus getting as much as possible out of the system. This becomes the drumbeat for the rest of the system that all the non-constraint operations are to match. In step 2, a production lead time is estimated between order release and the constraint. This is what is called the buffer. Note it is a time buffer and not a physical stock buffer. The purpose of the buffer is to ensure the constraint never runs out of work. In step 3, based on the output of the constraint orders are released. The amount of inventory between order release and the constraint, the rope, is determined by the constraint's drum beat and the buffer lead time.

Within DBR, it is implied that all non-constrained processes have a capacity that exceeds the constraint. This excess capacity is known in the TOC world as protective capacity. Because of this protective capacity, these non-constraint operations usually do not require production lot sizing different than that of the drum schedule or the schedule of the constraint. The sequence in which orders are prioritized within the operations is usually based on the consumption of the expected lead time. There exists a buffer management tool that is used in concert with DBR to monitor and analyze performance.

In general, when comparing MRPII to DBR, Polito, Watson, & Vokurka (2006) explained scheduling based on MRPII as counting backward from the end of the production line to determine workstation schedules as shown in Figure 1. The objective here is to keep all workstations busy.

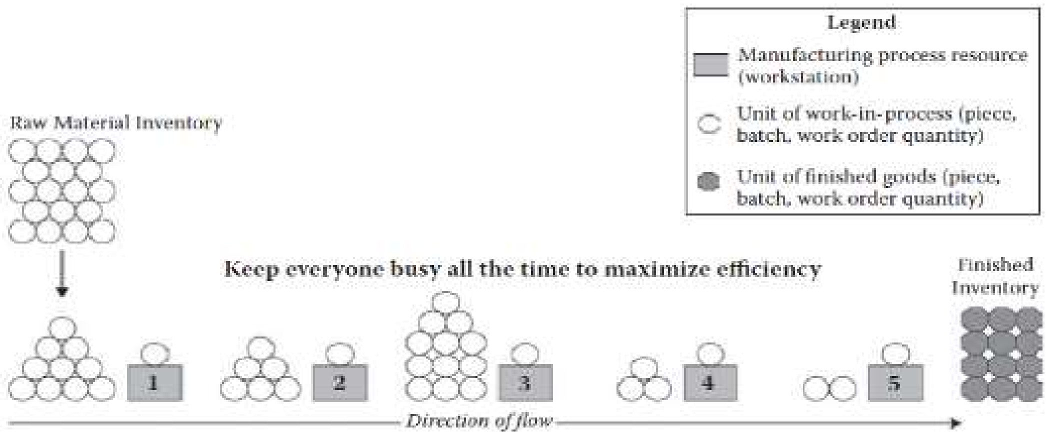


Figure 1: The WIP of MRP on the shop floor
Source: Schragenheim et al. (2009)

By contrast, scheduling based on DBR is established by counting backward from the bottleneck process as depicted in Figure 2. Here, the objective is to maximize the productivity of the bottleneck process. They stated that "The aim of TOC is to maximize the productivity of the entire system". Throughout the 1990's, contemplation of implementing DBR was on the rise (Koh & Bulfin, 2004). Today, a growing number of companies are implementing DBR. The DBR approach to production control appears to be on the rise. What follows is a case study on a part family that changed from an MRPII production control approach to an MRPII-DBR mixed approach.

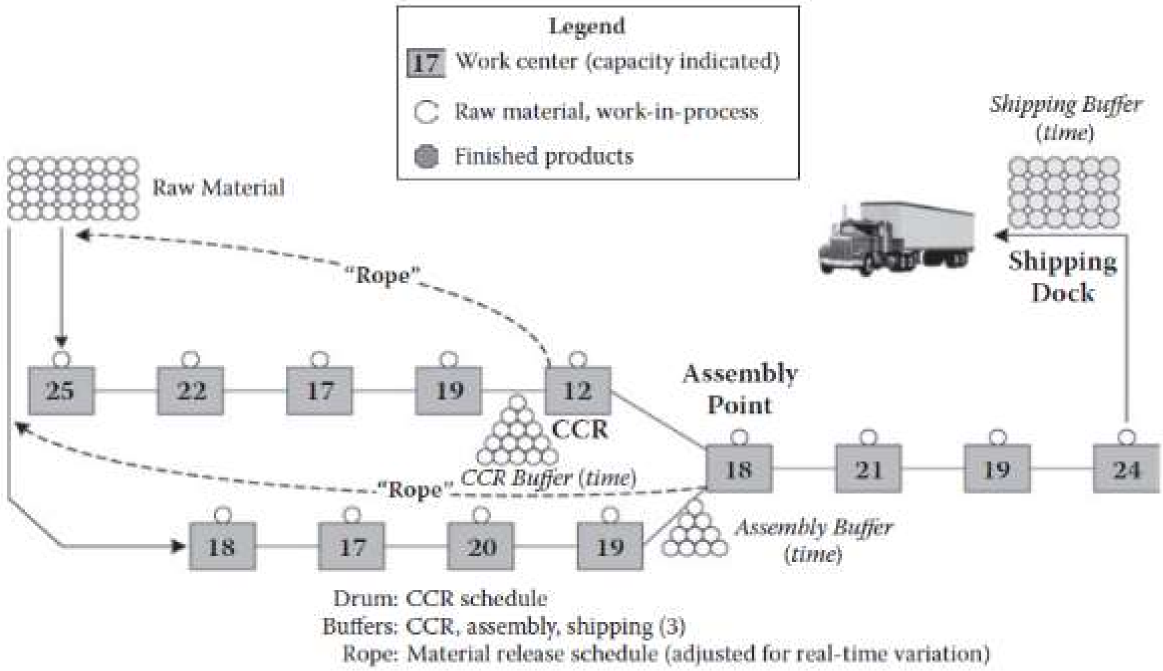


Figure 2: The Concept of the Drum-Buffer-Rope (DBR)
Source: Schragenheim et al. (2009)

3. Case study

Inventory levels at a local company, Z-Aero, were exceeding the executives' comfort levels. Z-Aero has a large production and assembly plant that was owned by a much larger company. It inherited the MRPII production control system and culture that was used by the much larger company. This culture included high inventory levels and low throughput. Z-Aero knew that in order to stay competitive they must reduce their inventory levels. Reducing inventory would free up cash, which could be used to invest in additional capacity to capture the market's growing demand. It could also provide the company a more competitive advantage by being able to respond quickly to the market's change in product requirements. As a result, the company strived to reduce inventory levels. With this goal in sight, the research team was given the initiative to reduce inventory for a specific part family; a part family whose raw material cost per part was significantly higher than other parts processed by the company.

The company's initial production control approach was MRPII-based. A master schedule was developed according to forecasts. MRPII production dates by operation were established based on lead times. Start and finish dates were established for each operation and were used to prioritize requirements within each shop. The MRPII expected lead time was 38.0 days, which was excessive to what was truly needed to satisfy flow. As a result, excessive inventory was released into the system at an average of 185 parts per day. This equated to $480 of raw material investment per day (coded for proprietary reasons). Yet, at the expense of aggressive expediting and utilization of high overtime, on-time delivery performance was satisfactory.

With the approval of the study, DBR was put to the test by determining the constraint of the production system. Initial analysis revealed that some operations were performed during one shift, while others were performed around the clock. Also, some of the operations were dedicated to the target part family, while others were shared with other parts.

	Met Flow	Exceeded Flow
Operation 1	73%	27%
Operation 2	5%	95%
Operation 3	50%	50%
Operation 4	48%	52%
Operation 5	40%	60%
Operation 6	80%	20%
Operation 7	78%	22%
Operation 8	73%	27%
Operation 9	79%	21%
Operation 10	84%	16%
Operation 11	33%	67%

Figure 3. Standard flow analysis

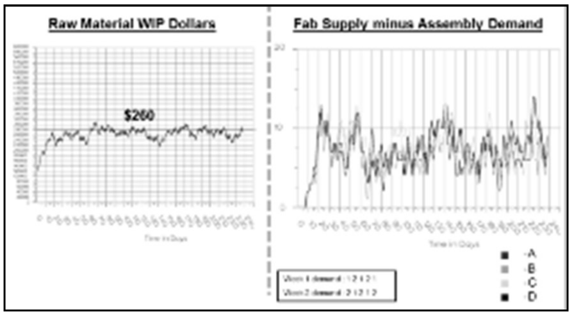
In identifying the true system constraint, flow was analyzed by comparing the MRPII expected lead time to the actual CT for each operation. Data from this analysis, shown in Figure 3, indicated that operation 2 was producing its parts 95% of the time longer than its MRPII lead time. This was significantly higher than any of the other operations, an indication that operation 2 was a constraint. Another way of identifying constraints within a system is by looking where inventory is stacked up. After reviewing the WIP levels of each operation, it was concluded that 30% of the system's inventory for this part family was in operation 2. All of the other operations carried anywhere from 2% to 15% of the total inventory at any given time. These results offered a confirmation that operation 2 represents the system's constraint.

With the constraint identified, the three steps of DBR could begin: 1) establish the drum beat, 2) determine the buffer time, and 3) establish the rope. As for step 1, demand was fixed and therefore the drum beat was already depicted. The demand for each part number within the part family, a set of four-part numbers, was 1.5 pieces per day. Therefore, the total drum beat was 6 pieces per day. The goal was to get operation 2 to produce 1.5 of each part number per day. All other operations were then to pace to this beat.

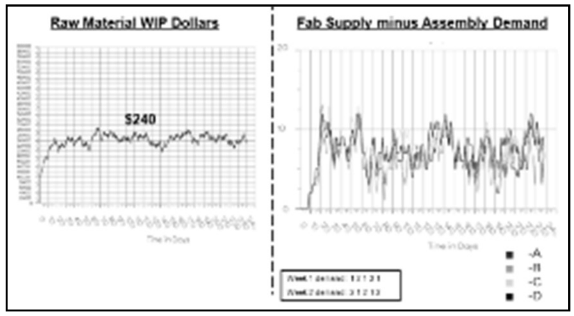
The second step was to determine the buffer time. This is the time used to protect the constraint from running out of work. Yet, for this study, due to the constraint being at the second operation, it was decided to use the time buffer for the entire flow of the parts. A target of 25% reduction in the current cycle time of 38 days was established by management. This resulted in a target buffer lead time of 28 days (38 days x 75% ≈ 28 days).

Step 3 of the DBR approach was to determine the rope. The rope was the signal to release more work into the system based on consumption at the constraint and the buffer lead time. Thus, the goal was to minimize the level of inventory needed in operation 2 to effectively utilize its capacity and satisfy the 6 pieces per day demand.

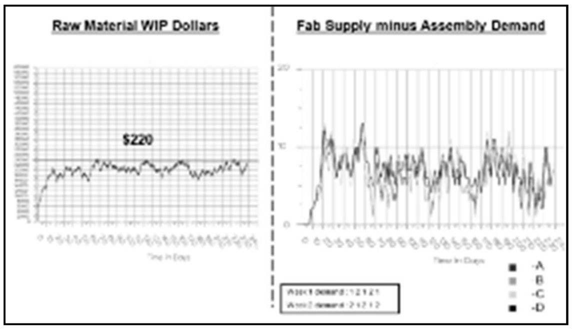
At its simplest form, DBR establishes a CONWIP between order release and the constraint (Schragenheim & Ronen 1990). Thus, utilizing this concept, the goal was to develop a simplified DBR between operation 1 (order release) and operation 2 (the constraint). With this concept, an order was not to be released into the system until one has exited operation 2. To help define the minimal CONWIP level needed to support the daily requirements, a simulation study using AutoMod® was performed. Distributions from historical performance data (output & machine downtime) were estimated and used to model the different operations. Responses of the simulation were inventory (in dollars) and finished goods buffer status (the difference between supply and demand). The only variable considered was the CONWIP level in operation 2. After verifying the model, a study was performed with no WIP to validate its performance. Finally, the model was run with different levels of CONWIP to identify the level needed to satisfy delivery and minimize inventory. Examples of the results over 240 days are represented in Figure 4.



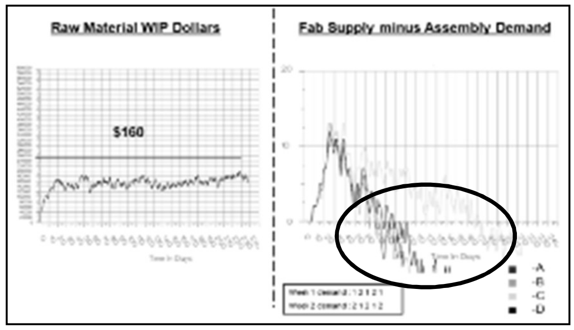
(a) CONWIP level of 12 satisfies demand



(b) CONWIP level of 10 satisfies demand



(c) CONWIP level of 6 satisfies demand



(d) CONWIP level of 4 fails to meet demand

Figure 4 – CONWIP simulation results

Each graph indicates the inventory level (in dollars) on the left, and the finished goods buffer status on the right. As can be seen, by maintaining a CONWIP of 6 pieces or higher for each part number, the system was able to sustain a healthy finished goods buffer. However, once the CONWIP was reduced to 4, the system was no longer able to satisfy delivery requirements as shown in Figure 4(d). The finished goods buffer depleted overtime as operation 2 was not able to meet daily demand requirements. This indicated that a CONWIP level of 4 pieces was too low. Thus, the best outcome was a CONWIP level of 6 where the inventory level for the system was at its lowest while being able to satisfy customer delivery. At this level, inventory could drop from $480 to $220 per day, a 54% reduction.

To monitor the performance of the system during implementation, a buffer report was designed to measure the consumption of the buffer lead time as shown in Figure 5.

Order	Op1	Op2	Op3	Op4	Op5	Op6	Op7	Op8	Op9	Op10	Op11	Op12
100594	3	14	16	18	30	31	32	64	128	-	-	-
105491	1	20	21	22	30	36	69	64	-	-	-	-
110014	1	18	19	21	30	36	67	62	-	-	-	-
110516	1	25	26	30	31	32	33	36	49	-	-	-
112901	1	27	28	31	31	32	33	35	-	-	-	-
113554	1	22	23	25	27	31	33	34	-	-	-	-
119436	3	21	24	29	29	33	33	37	39	40	40	-
119841	3	22	24	26	27	33	34	38	40	-	-	-
122188	3	22	25	27	31	39	-	-	-	-	-	-
125021	1	28	29	30	31	36	37	-	-	-	-	-
129539	1	28	30	31	34	36	-	-	-	-	-	-
129646	1	29	30	32	34	35	-	-	-	-	-	-

(a) Initial state

Order	Op1	Op2	Op3	Op4	Op5	Op6	Op7	Op8	Op9	Op10	Op11	Op12
170635	1	4	7	9	13	16	18	21	-	-	-	-
171866	1	4	8	9	10	11	14	16	19	21	-	-
171970	2	5	7	9	11	15	17	18	20	-	-	-
172059	2	5	7	8	9	13	13	16	19	20	20	
173816	1	3	7	8	9	10	12	15	-	-	-	-
174862	1	4	8	8	9	10	12	12	-	-	-	-
179822	2	3	7	8	9	10	12	12	-	-	-	-

(b) Two months after implementation

Figure 5. Buffer reports

Across the top of the report (the columns), are the different operations where the selected parts were produced. Along the left side of the report (the rows), are the individual part numbers of each open order in the system. The cells contain the number of days that an order had been in the system at the time it exited the process associated with the column. When reading across a row from left to right, the last cell with a value represented that the order associated with the row is currently queued in the process associated with the column. The value in this cell represents the total duration that the part had been in the system.

The cycle time of the parts selected had an average of 38 days. With the initiative to reduce the initial cycle by 25%, the new goal was 28 days. The buffer time has been divided into three equal zones: green, yellow, and red. The three zones for this study were: 1-9 days (green), 10-18 days (yellow), and 19-28 (red). During implementation, each operation is to run FIFO with no special action taken until a part reaches either the yellow or red zone. When an order reaches the yellow zone, an action is taken only if the order is at the beginning of its routing. When an order reaches the red zone, an action such as overtime, subordination, or other means is used to push it through the system. The buffer reports shown in Figure 5 were prepared such that any cell that exceeded 19 days is highlighted.

With the DBR approach fully defined and a report developed to monitor performance, the next step was to implement the solution. Order release was set on hold until each part number in process 2 was at a WIP level of 6. All operations that were dedicated to producing this set of parts were to work to the priority of the buffer report. Other operations complied with the MRPII start and finish dates. Expediting took place if the buffer consumption reached the red zone. Operation 2 was to work a half shift on Saturdays to maintain the 6 pieces per day demand. Results of this implementation over a period of two months are shown in Figure 5 (b). As shown, the number of orders to be expedited was significantly reduced as compared to the initial state. Both inventory and cycle time of the selected parts decreased significantly while maintaining on-time delivery at stable levels. Prior to implementation, CT was averaging 38 days. After implementation, CT averaged 28.8 days, a 24% decrease. As a result of increasing the velocity of the parts through the system, WIP decreased as well. Inventory levels were reduced from an average of 185 to 105 parts at any given time. This equated to a 43% reduction in inventory. On-time delivery was maintained while CT and WIP significantly decreased as a result of integrating DBR concepts into the current MRPII system.

4. Conclusions

Utilizing DBR with the MRPII system did result in an improved response capability for the selected parts. MRPII is a great management tool for in-plant scheduling, production planning, machine capacity scheduling, and demand forecasting. It is a tool that provides a priority based on inputted lead times and a master schedule. It is not, however, a methodology for controlling throughput, inventory, and cycle time. Within MRPII systems, these rapid response factors become a result of the input provided by users. As demonstrated in this case study, MRPII can be coupled with rapid response methodologies such as DBR. The tools within MRPII did support the DBR concepts chosen for implementation. In general, this study indicated that full DBR implementation is not needed to reduce inventory and cycle time. Integrating DBR concepts within MRPII systems can significantly improve a company's response capabilities.

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Optimization of Warehouse Material Handling Parameters to Enhance the Efficiency of Automated Sorting and Storage Systems

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Abstract

This paper studies the influential parameters, which affect the efficiency of an Automated Sorting and Storage System (ASSS) in an automated carpet warehouse. For the purpose of this research, the efficiency is defined as the utilization of the sorting mechanism queues; the utilization of the Automated Guided Vehicles (AGVs); and the average sorting and storage time. The controllable parameters studied are the number of sorting queues, number of AGVs and the production rate. A typical layout of an automated carpet warehouse has been devised, modelled and simulated using a specialized software, Flexsim. Results indicate that all factors including higher order interactions significantly affect the response factors (sorting and storage efficiency). Following this, non-linear optimization was used to maximize the sorting and storage efficiency by controlling the controllable system factors.

1. Introduction

Optimization is the process of reaching the optimum solution for a certain problem or reaching optimum production (Foulds, 2012). Optimization ensures that all of the processes conducted in any facility, such as manufacturing plant or warehouse, are not time or energy consuming, and are economically feasible. In other words, it makes sure that every process is as efficient as possible. The case under consideration is the carpet warehouses. Having a warehouse to function in an efficient manner that is synchronized with other manufacturing facilities is critical in the carpet industry. The reason being that in the carpet industry, it is difficult to estimate demand as it is seasonal and rises and drops rapidly (Fan and Zhou, 2018). For that reason, modelling such problems requires the use of probabilistic or stochastic process variables. Additionally, carpets as bulky items are costly to manoeuver in the warehouse. As such, Automated Guided Vehicles (AGV) are normally chosen as the material handling device. Therefore, there is a need to render the movement in the warehouse as efficient as possible. The carpets need to be stored and shipped, with the highest level of AGV utilization consuming the minimum sorting and storage time.

The aim of this research is to identify the optimum process parameters to enhance the efficiency of the motion of the carpets inside the warehouse. The two most important of these are; the number of AGVs and the number of sorting queues feeding the AGVs from the production departments at different production rates.

2. Review of optimization of warehouses

Various techniques have been developed to be used in warehouse optimization (Dotoli et al., 2015). These may be utilized either individually or combined as will be subsequently illustrated. The mostly commonly adapted techniques in warehouse optimization are:

- Value Stream Mapping (VSM): a method used to map production flow visually and show the present and future state of processes while highlighting room for improvement through minimizing non-value adding activities.
- Gemba: refers to the real place or specific place. This approach is similar to that of VSM, in that it focuses on waste identification and removal; Gemba in lean methodology refers to the location within the workplace where value is created.
- Bottleneck analysis: focuses on identifying the elements of the manufacturing process, which limit the general throughput, and to improve the performance of these elements.
- The Unified Modelling Language (UML): a method of representing the system activities in detail. This can be through a static structural view using objects, operations and relationships or through a dynamic behavioral view showing changes to the internal states of objects.
- Kaizen: stands for a proactive strategy for attaining continuous improvement through identifying problems prior to occurrence.
- Muda (waste) removal: it focuses on eliminating anything in the manufacturing process, which does not add value from the customer's perspective.
- Plan, Do, Check, Act (PDCA): is an iterative methodology for applying continuous improvement of processes and products.
- Root cause analysis: is a problem-solving method that focuses on resolving the primary problem instead of focusing on the symptoms.

In most modern warehouses, rather than using an individual optimization technique, an integrated approach is taken. The integrated approach involves utilizing several different techniques in a certain order, so that the optimum outcome from the warehouse is attained. An example of such an integrated approach indicating the flow of the optimization process is as follows: Initially, UML is utilized to describe the warehouse activities in detail, indicating each element of the system. Subsequently, the VSM is used to identify all of the anomalies, which occur in any of the processes contained in the system pinpointing the non-value added activities. Consequently, the Gemba technique is used to rank the anomalies that have been identified using the VSM tool. This gives an overview of the most critical non- value-adding processes, which need to be removed. Then the VSM tool is used again to determine whether there are still other anomalies, which may have not been identified. This step may be iterated successively until no anomaly is present in the system except those that may occur due to uncontrollable factors. The UML is then used once again to redraw the final description of the complete system. The final step is to reengineer the warehouse.

In optimization of warehouse management, it is required to consider the synchronization of the technological, transport, store and service operations through the process of logistics chain to obtain harmonious flow of material. This flow commences from the provider of raw material up to the consumer through the manufacturer, in the fastest time, at the minimum cost and with the required quality and quantity. The logistics chain involves subsystems that are made up of different processes and activities. In the warehousing subsystem particularly, processes are related mainly to income and expenses but also related to other processes such as packing, sorting, labelling and others. In order to optimize these processes, mathematical models are applied to be part of the decision making and management of logistics (Masek, et al., 2015). Among the numerous models developed, queueing theory is the most commonly utilized as it is the most fit to handle bottlenecks in warehouses. Additionally, it considers each process as part of the logistics system not just as an isolated subsystem. Queueing theory is defined as the mathematical study of queues or waiting lines. In queueing theory, a model is constructed so that queue lengths and waiting times may be predicted.

While applying the queueing theory to carpet warehouses, consideration must be made of the arrival process of the products namely carpets to be stored or shipped, and the service mechanisms namely carpet handling equipment. As the arrival of carpets according to design, size and material is random, the arrival usually adopts a Poisson stream. The service equipment are; the Automated Guided Vehicles (AGV), conveyors used for moving the carpets from one place to another, or the Automatic Storage/Retrieval System (AS/RS).

An additional key component crucial for warehouse optimization is the layout design as it impacts the travelling distances and order picking. It has been suggested that layout design has more than a 60% effect on total travelling distance therefore having a significant influence on cost savings (Karasek, 2013).

Factors to be considered in the layout design include; the number of picking stations along with their length and width, the number of rack levels, and the positions of the in and out gates of the warehouse (Karasek, 2013). Different types of storage policies are applicable in warehouses. These are; random storage, class based storage and dedicated storage (Dharmapriya and Kulatunga, 2011). In random storage, the first available space is allocated to incoming products. This leads to a compactness of the storage space leading to better space utilization but leads to inefficient material handling. This method is generally utilized for products that are often needed or ordered. Class based storage however tackles this issue by partitioning the storage area into different classes based on groupings of products. Within each class, the products are randomly stored based on availability of slots. Frequently ordered products are placed in better reach and the less frequently ordered products are placed further away. The classes are classified according to popularity, size and accessibility of each product. In dedicated storage, each product is allocated a fixed number of maximum locations reflecting the utmost storage need. In the carpet industry, which is very dynamic in nature, a combination of dedicated and class-based storage is utilized. This adds flexibility due to changing storage and handling requirements, provides an economical path for order collection, and offers economical storage in relation to retrieval and space utilization. The selection of an appropriate policy will determine how operations in the warehouse are conducted such as storage and order picking (Goetschalckx and McGinnis, 2010).

3. Optimization of AGV motion

There are two main aspects concerning the motion of the AGV, which are the scheduling and the routing. Both aspects need to be optimized in regards to the motion time and loading factor. The automated carpet warehouse requires a strict scheduling timeframe, which needs to be followed. The AGV interacts both with the conveyor subsystem and with the AS/RS. An un-optimized AGV motion will lead to build-up of queues, cause the collapse of the harmonious operation of the warehouse, or result in deficient utilization of resources. One of the main issues affecting the optimization of the AGV motion is the availability of the sorting queues and the location of the pickup and drop-off points of the AS/RS (Fazlollahtabar and Saidi-Mehrabad, 2015). Suggested techniques utilized to efficiently schedule AGV motion are: dynamic loading, differential evolution heuristic approach, Adaptive Genetic Algorithms (AGA) method, and Evolutionary Algorithm (EA). Dynamic loading involves the AGV handling multiple loads. This will add value to the facility by minimizing the travel time and the number of laps the vehicle travels between jobs. Additionally, it offers the ability to deal with unexpected changes in the system due to its dynamic nature (Sinriech and Kotlarski, 2002). On the other hand, the differential evolution heuristic approach depends on determining the optimum schedule based on the current properties of the problem itself. This heuristic decreases the make-span of the schedule between production machines and the material handling system (Kumar et al., 2011). Regarding the AGA method as applied to schedule multiple AGVs in warehouses, each AGV is to make stops at each pickup and drop off location while reducing the queue size and the idle time (Jerald et al., 2006). Finally, concerning the EA, it is used to determine an optimal schedule for two contradictory objectives simultaneously (Sankar et al., 2006).

Regarding the routing of the AGV, finding the optimal route is crucial so that it makes the least number of trips possible. The product being moved through the warehouse also needs to have the least amount of average waiting time. Two routing algorithms are commonly used with AGVs, namely static routing and dynamic routing. Employing static routing algorithms, the warehouse area where routing takes place is divided into nodes. The route of one node to another is fixed and known in advance. It is always consistent and used repeatedly when it is desired to transport a product between these nodes. This provides a simple method for finding the optimal route with minimum computation time and power. However, this method lacks the ability to adapt to unexpected scenarios such as unplanned traffic in the AGV path (Fazlollahtabar and Saidi-Mehrabad, 2015). On the other hand, in dynamic routing, real time information from the system itself is used to formulate routing decisions. It acts as a closed loop system continually searching for the optimal route to be taken through combining individual route fragments. For warehouses with multiple AGVs, dynamic routing may suffer from traffic deadlock due to AGVs facing each other.

4. Development of an automated carpet warehouse layout

In order to design the layout of the automated carpet warehouse, the carpet motion processes must be appreciated. In order, these are: identification, sorting, batching, transportation, storage and shipping. The carpets are received at the entrance of the warehouse from various manufacturing stations with a specific production rate through an input conveyor. The conveyor includes a barcode identifier, which recognizes the carpet. Subsequently the carpet is then delivered to the sorting conveyor, which branches out into straight conveyors, one for each identified type of carpet. At the end of each branch, a carpet collection box is placed to receive the sorted carpets, batch them into boxes, and transfer the boxes to the sorting queue. Once an AGV arrives at the sorting queue, it either transports the boxes to the storage area i.e. the AS/RS or directly to the shipping area.

A sample designed layout, as simulated in the Flex-Sim discrete event simulation software (Flexsim Software products), is illustrated in Figure 1 below. The carpets are input onto an oval sorting conveyor fitted with barcode readers. The oval design not only is compact, but also allows the carpets to continuously rotate after been identified if the sorting queues are full. Therefore, bottlenecks are avoided during the identification and sorting process. The straight conveyors transfer the identified carpets to their allocated box, which is added to the AGV queue. Subsequently, once the AGV is free, it picks up carpet boxes from the queue and transports them either to immediate shipping or to storage in the AS/RS.

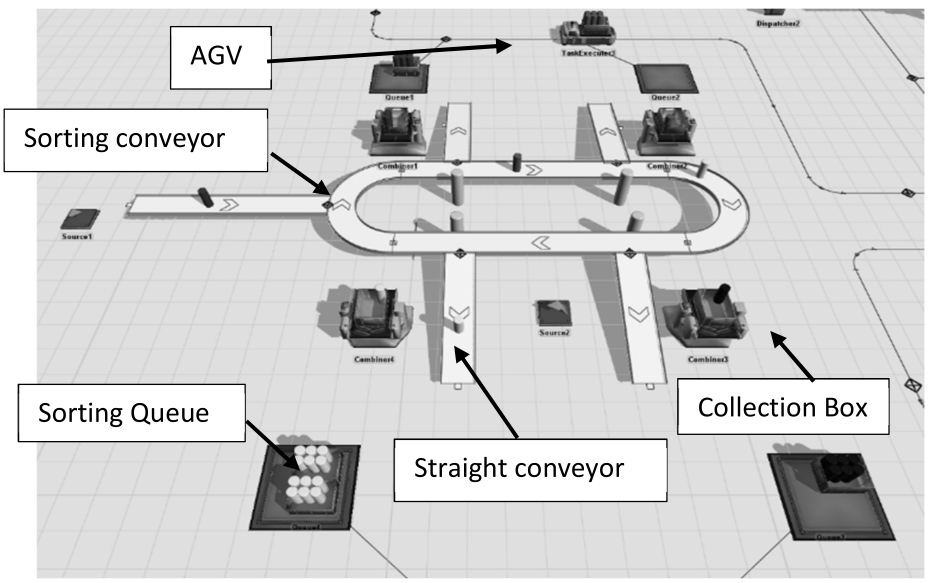

Figure 1. Designed carpet manufacturing layout

5. Process controllable and efficiency parameters

Enhancing the efficiency of the process of Automated Sorting and Storage will require minimizing the number of AGVs and the number of sorting queues while achieving minimum sorting and storage time. The controllable factors in this problem are: the number of AGVs, the number of sorting queues and the production rate of the carpet coming from the manufacturing facility to the warehouse. The controllable factors are varied in a pre-specified manner, and its effect on the utilization of both the AGVs and the sorting queues, and the sorting and storage time are studied which contribute to the process efficiency. This is shown in section 6 below. To reduce the complexity of the model, a number of assumptions took place in order to achieve the optimum solution. The maximum capacity of each AGV is set to one box. In addition, each sorting box can only carry six carpets. The capacity of each sorting queue is set to two boxes. Section 5.1 and 5.2 below illustrates the controllable as well as the response factors. Controllable factors are the factors that can be varied to study their effect on the response factors with the main aim of optimizing these response factors.

5.1. Controllable factors

In this research, the controllable factors studied are the number of AGVs; number of sorting queues and production rate. These factors can be defined as follows:

A. Number of AGVs

AGVs are guided vehicles that take the carpets from the sorting queues and transfer them into the storage racks. Increasing the number of AGVs, reduced the storage time but again raised storing cost.

B. Number of sorting queues

These queues are used to sort the carpets based on type after coming from the manufacturing facility. Increasing the number of sorting queues will help the sorting process to go smoother and quicker resulting in more financial charges but reducing the sorting time.

C. Production time

The carpet manufacturing is a complicated process that have many factors affecting its production rate. Part of these factors is the seasonality of the product and the production type whether it is make to order or make to stock. When the production rate increases, increasing the number of AGVs and the number of sorting queues is necessary. For the purpose of this research, the production time is the time it takes a carpet to enter the sorting area coming from all over the manufacturing facility and not just from one specific machine or plant. It is easily noted that factors A and B are discrete factors while factor C is a continuous factor and this should be taken into consideration when analyzing this factor and during the optimization process.

The above factors are allowed to vary deliberately in order to assess its effect on the response factors shown in Section 5.2. The controllable factors were selected according to the importance and effect of a certain parameter based on previous knowledge. In this research, the number of levels is limited to three levels as listed in Table 1 below.

Table 1. Design factors and levels

Factor	Units	Low	Meduim	High
Number of Sorting Queues		4	6	8
Number of AGVs		4	6	8
Production Time	sec/carpet	2	5	10

5.2. The response factors

The efficiency of the sorting and storage process or system will be affected by the utilization of the AGVs and the utilization of the sorting queues besides the average sorting and storage time. Thus to ensure high effectiveness in the sorting and storage process or system, utilization of the AGVs and the sorting queues need to be maximised at the minimum allowed sorting and storage time.

A. Utilization of sorting queues

This is the average utililization of all of the sorting queus in the system for specific period of time. The utilisation of each sorting queue is calculated numerically as the ratio between the time where the queue is operating to the total time including operating and idle time. A

B. Utilization of AGVs.

This is the average utilisation of all the AGVs in the system for specific period of time. The utilisation of each AGV is calcualted numerically as the ratio between the time where the AGV is operating to the total time including operating and idle time.

C. Sorting and storage time

This is the average time it takes a carpet from the time it enters the automated sorting and storage area until it reaches the warehouse racks.

6. Analysis of efficiency factors

This section aims to discuss and analyze the results of modeling the carpet sorting and storage process or system as a 3-Factor factorial design (three controllable factors, at three levels each). The section describes the analysis of variance (ANOVA), reduced model, model adequacy check, regression model of results, and finally, an optimization attempt is made on the response variables.

6.1. Utilization of the sorting queues

This is the first response that contributes to the overall effectiveness of the automated sorting and storage process or system. The Flexsim simulation software computes the average utilization of all of the sorting queues as the total amount of time the sorting queues are operating (receiving carpets and transferring them to the AGVs) to the total process time (Operating and Idle time). The idle time in this case is due to the fact that the production facility is not producing any new carpet or the sorting queues are full and waiting for any free AGV to pick up its load from the sorting queues. The data was entered and analyzed in Design-Expert 9.0.6. Note that all analysis inferences are based on a significance level of $\alpha = 0.05$. This paper utilizes the p-value technique to judge significance due to simplicity of use. If p-value $< \alpha$, then the factor effect is significant.

6.1.1 Analysis of variance: Analyzing this factor revealed that all three factors' interactions were found to be not significant and thus removed from the model. The authors of this paper decided to ignore higher factors interactions due to their lack of significance. In addition, some quadratic factors (A^2, B^2, and C^2) were found significant and thus 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 sorting queues

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	16360.36	9	1817.82	211.57	< 0.0001
A-Number of AGVs	55.20	1	55.20	6.42	0.0214
B-Number of Sorting Queues	1610.91	1	1610.91	187.49	< 0.0001
C-Production Time	10396.82	1	10396.82	1210.04	< 0.0001
AB	136.69	1	136.69	15.91	0.0010
AC	307.84	1	307.84	35.83	< 0.0001
BC	180.01	1	180.01	20.95	0.0003
A^2	204.17	1	204.17	23.76	0.0001
B^2	64.03	1	64.03	7.45	0.0143
C^2	1909.62	1	1909.62	222.25	< 0.0001
Residual	146.07	17	8.59		
Cor Total	16506.43	26			

By diagnosing the residual plots, the distributions are found to be independent and follow the Normal distributions 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.

6.1.2. 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 (R^2) of 0.992, 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 model factors and the response factors is generated to be used for prediction purposes to predict the utilization of sorting queues at any of the values of the process parameters (A, B, and C). The regression prediction model (Eq. (1)) expressed in the actual process factors is:

Utilization of Queues =
+156.5 -17.08* Number of AGVs -6.6* Number of Sorting Queues + 7.5* Production Rate -0.84* Number of AGVs * Number of Sorting Queues + 0.63*Number of AGVs * Production Rate - 0.48* Number of Sorting Queues * Production Rate +1.46* Number of AGVs^2 +.82* Number of Sorting Queues^2-1.20*Production Rate →(1)

6.1.3. Response surface plot of utilization of the sorting queues: The design expert software aids in the generation of both the response surface and the contour plots using the equation generation in Sub-Section 6.1.2 above. Both graphs (Figure 2) illustrate how to maximize the utilization of the sorting queues to enhance the system effectiveness. The graphs show that the utilization increases when we increase the number of AGVs and reduce the number of sorting queues. This is very logical because when we increase the number of AGVs, this in turn reduces the blockage time of the sorting queues allows it to take more carpets for the manufacturing facilities. Thus, to maximize the utilization of the queues we should minimize the number of sorting queues and maximize the number of AGVs. It is worth saying that reducing the time it takes to produce a carpet from 10 to 2 sec / carpet, tremendously increases the utilization of the queues.

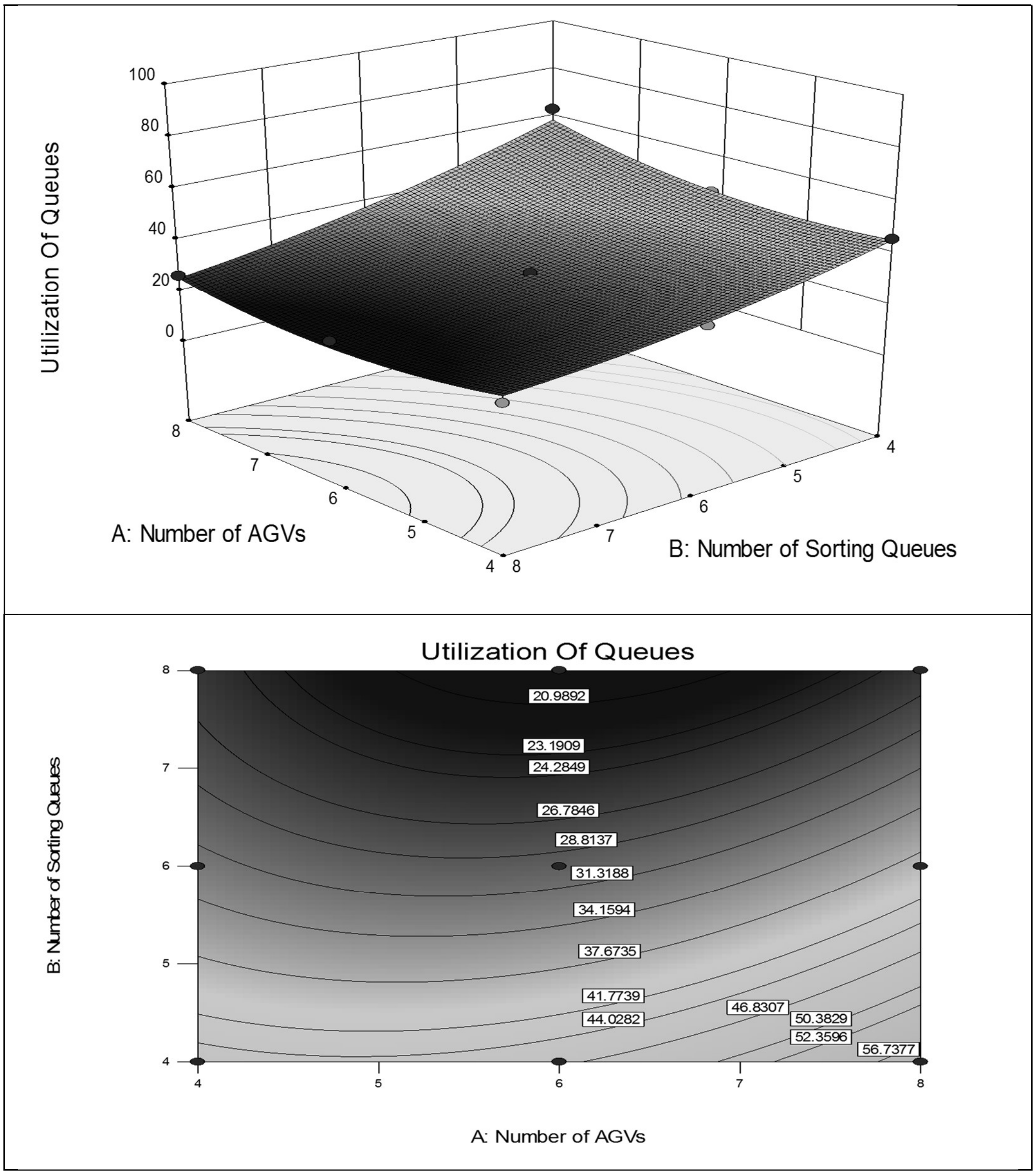

Figure 2. Response surface and contour plots for the utilization of sorting queues

6.2. Utilization of AGVs.

The utilization of the AGVs is much affected by the time the AGVs are not working or are so called idle, which is due to the fact that no boxes are available at the sorting queues to be picked up. This strengthen the fact that more AGVs are available in the system than the required number of AGVs. Having more AVGs than required results in more production cost. Again, the data was entered and analyzed in Design-Expert 9.0.6. Note that all analysis inferences are based on a significance level of alpha of 0.05.

6.2.1 Analysis of variance: Analyzing this factor revealed that all three factors interactions were found to be not significant and thus removed from the model. Only one 2 factor interaction (AC) was found significant and included in the model. The authors of this paper decided to ignore higher factors interactions due to its lack of significance. In addition, some quadratic factors (A^2 and C^2) were found significant and thus included in the model. Thus the resulting model is shown in the Analysis of Variance (ANOVA) table below (Table 3).

Table 3. Reduced ANOVA for the utilization of AGVs

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	7799.29	5	1559.86	585.33	< 0.0001
A-Number of AGVs	3920.41	1	3920.41	1471.11	< 0.0001
C-Production Time	2805.00	1	2805.00	1052.56	< 0.0001
AC	15.79	1	15.79	5.93	0.0239
A^2	14.00	1	14.00	5.26	0.0323
C^2	528.74	1	528.74	198.41	< 0.0001
Residual	55.96	21	2.66		
Cor Total	7855.26	26			

6.2.2. Regression model: The obtained model shown in Table (3) above results in a correlation coefficient of 0.993 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, which illustrates the relationship between the model factors and the response factors is generated to be used for prediction, purposes to predict the utilization of AGVs at any of the values of the process parameters (A, B, and C). The regression prediction model (Eq. (2)) expressed in the actual process factors is:

Utilization of AGVs = +138.2 -12.85*Number of AGVs + 3.62*Production Time + 0.14* Number of AGVs * Production Time + 0.38*Number of AGVs^2 - 0.6*Production Time^2 →(2)

6.2.3. Response surface plot of utilization of the sorting queues: The design expert software aided in the generation of both the response surface and the contour plots using the equation generation in the Sub-Section 6.2.2 above. Both graphs (Figure 3) illustrate how to maximize the utilization of the sorting AGVs to enhance the system effectiveness.

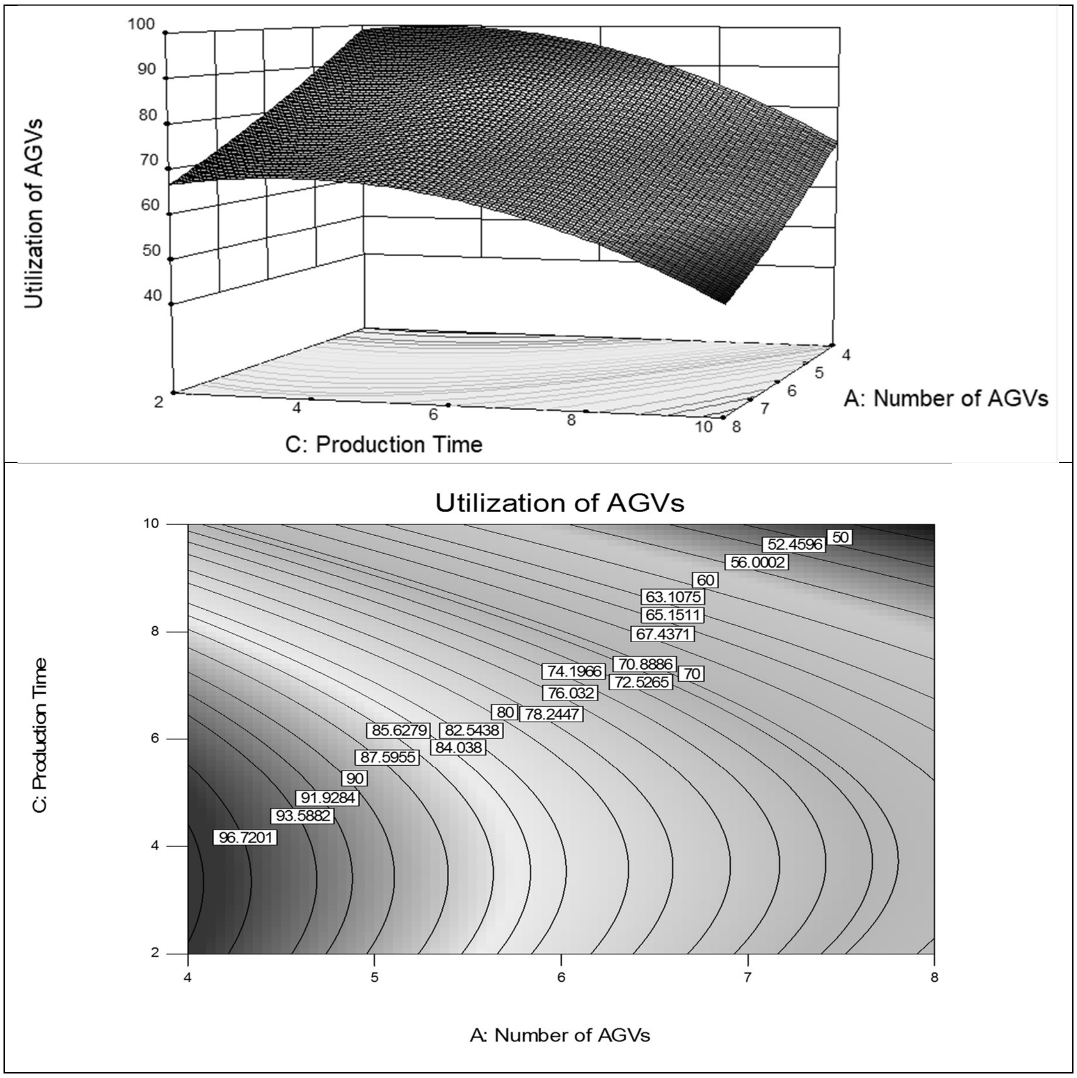

Figure 3. Response surface and contour plots for the utilization of AGVs

The graphs show that the utilization increases when we reduce the number of AGVs at any specific value of production time. This is very logical because when we increase the number of AGVs, this in turn increases its idle time because more AGVs will be used to transport the boxes and thus there will be time where no more boxes are available for transportation to the storage rack. It is worth saying that the above response surface and contour plots are generated when the number of sorting queues are at its average point (6 sorting queues). This is still a good illustration of the data since this factor (number of sorting queues) was found not to be significant and thus the graphs will not differ when we change the number of sorting queues whether to be at 4 or 8. Thus, to maximize the utilization of the AGVs we should minimize the number of AGVs for any specific production time. It is worth saying that reducing the time it takes to produce a carpet from 10 to 2 sec / carpet, tremendously increase the utilization of the AGVs.

6.3. Sorting and storage time

The last but not least response (third epxerimental objective) is the sorting and storage time, which is required to be minimized in order to enhance the productivity within the ASRS. This time can be defined as the average time that it takes a carpet from entering into the ASRS until it reaches the storing racks passing through all of the steps of sorting, boxing in the sorting queues, and transportation by the AGVs into the storage racks. Table 4 below shows the AVOVA for the Sorting and Storage time. It illustrates that sorting and storage time is only affected by the number of AGVs and the production time. This is also shown in the regresssion prediction model shown in Equation (3).

Table 4. Reduced ANOVA for the utilization of sorting and storage time

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	1487.91	4	371.98	73.55	< 0.0001
A-Number of AGVs	59.81	1	59.81	11.83	0.0023
C-Production Time	1020.77	1	1020.77	201.84	< 0.0001
A^2	63.05	1	63.05	12.47	0.0019
C^2	190.45	1	190.45	37.66	< 0.0001
Residual	111.26	22	5.06		
Cor Total	1599.17	26			

Equation (3) can be utilized to calculate the sorting and storage time for any specific production time while using a certain amount of AGVs. The correlation coefficient (R^2) for the above model is found to be equal to 0.93, which reveals excellent model for prediction of the response factor.

Average Sorting Time = +8.75 + 10.64*Number of AGVs + 2.67*Production Time - 0.81*Number of AGVs^2 - 0.38*Production Time^2 (3)

Figure (4) below shows the response surface and the contour plots by plotting Equation (8), average sorting time as a function of the number of AGVs and production time. At any production time (low, 2 second per carpet or high 10 seconds per carpet), the minimum average sorting time was achieved at 4 AGVs.

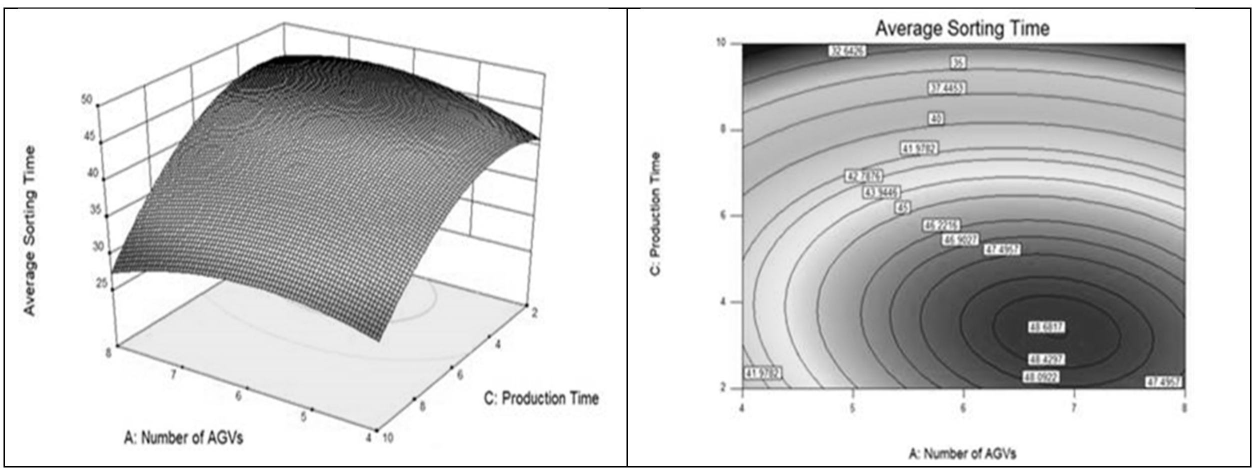

Figure 4. Response surface and contour plots for the sorting and storage time

6.4. Optimization of the sorting and storage efficiency

This section focuses on the optimization of the sorting and storage parameters that affects its efficiency including the utilization of the sorting queues, the utilization of AGVs, and the sorting and storage time. Thus Equation (1), (2) and (3) will be numerically optimized to achieve the optimum solution that maximizes the utilization of both the sorting queues and the AGVs and minimizing the sorting and storage time. It will be performed at different production times (2 sec/carpet; 5 sec/carpet; and 10 sec/carpet). The optimization model will run as shown in Figure (5) below.

Usually, the main objective of any carpet manufacturing company is the productivity which is most explained in terms of the time it takes to sort and store the carpet, thus the sorting and storage time was given double the importance of the other two criteria (utilization of sorting queues and utilization of AGVs). Table (5) shows the output of this analysis.

Maximize Utilization of Sorting Queues (**)
Maximize Utilization of AGVs (**)
Minimize Sorting and Storage time (****)
S.T.
4≤ Number of Sorting Queues ≤ 8
4≤ Number of AGVs ≤ 8
Production Time = 2, 5, and 10

Figure 5 The Optimization of the Sorting and Storage Efficiency

The (*) beside the objective function illustrates the importance of this function as compared to other objective functions.

Table (5) Optimization of the Sorting and Storage Efficiency

Production Time	Optimum Solution		Achieved Output		
	Number of AGVs	Number of Sorting Queues	Utilization of Sorting Queues	Utilization of AGVs	Sorting and Storage Time (sec/carpet)
2 sec/carpet	4	8	91.44	98.767	40.515
5 sec / carpet	4	8	84.8	98.04	41.637
10 sec/carpet	4	4	45.6	71.53	28.98

The analysis shows that it is always desirable to have 4 AGVs whether the production time is low or high. Except for the case of a very low production rate (high production time, 10 sec per carpet), it is satisfactory to use 8 sorting queues. If the production time is always greater than or equal to 10, the automated sorting and storage system can work efficiently with only 4 sorting queues.

Although it seems somehow predictable that the utilization of the AGVs and the sorting queues can be maximized by minimizing the number of AGVs and the sorting queues, the results above show that this can be achieved with a minimum number of AGVs and a maximum number of sorting queues (8 sorting queues), except for the case when the production is very slow. This is because three response variables are being optimized in this model.

This model and its subsequent results can be used by practitioners in the area of carpet manufacturing to determine the number of AGVs and the number of sorting queues that should be utilized to maximize the utilization of the sorting queues and the AGVs and minimizing the time it takes to sort and store the carpet.

7. Conclusion

In conclusion of the above research, the following conclusion can be drawn:

- The number of AGVs; the number of Sorting Queues; and production time affects the efficiency of Automated Sorting and Storage System (ASSS). This efficiency is defined as the utilization of the sorting queues (needs to be minimized); the utilization of the AGVs (needs to be maximized) and the average sorting and storage time (needs to be minimized).
- Controlling process parameters resulted in enhancement in the efficiency of the ASSS. Numerical optimization was found beneficial to enhance the efficiency of the ASSS.
- Higher order combinations of the controllable factors also affect the efficiency of the System.
- A regression model can be formulated to predict the response factors as a function in the controllable factors

As an extension of this research, other process factors including the possibility of the AGVs to carry more than one box, and increasing the size of the sorting boxes could be explored to enhance the efficiency of the ASSS.

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Studying the Effect of Computational Material Modeling Parameters on the Determination of Mechanical Properties at Molecular Level of Cement

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Abstract

Cement-based materials, specifically including cement paste, mortar, and concrete are the most widely used, manufactured product in the field of construction. Cementitious materials have complex hierarchical structures with random features that range from nanometer (nm) to millimeter (mm) scale and beyond with each length scale representing a new random composite. Experimentation and laboratory testing is used to characterize the stiffness of cement-based materials at the engineering length scale. Laboratory testing is, however, inefficient and impractical toward understanding mechanical properties of composites at the molecular scale level. Recently, Computational Material Science (CMS) has made rapid improvements. Computational Modeling (CM) based on the Molecular dynamics (MD) Method provides a useful methodology for studying the behavior of cementitious materials at the molecular level. Many parameters are considered when running CM simulations. Periodic boundary conditions (PBC), type of ensemble, pressure control methods, temperature control methods, time step, dynamic time, and cutoff distance are some of the many essential parameters considered, and defined, through molecular dynamics analysis. The choice of the values of each of these parameters has a significant effect on the results. The impact of these parameters mentioned on the mechanical properties and a discussion of the many simulation-modeling parameters, as noted above, will be the focus of this paper.

1. Introduction

Cement is the most used manufactured material worldwide (Allen, 2007). Cementitious materials are cement-based materials such as cement paste, mortar, and concrete. Cementitious materials have complex hierarchical structures from nanoscale to macroscale. Processes occurring at the nanometer scale affect the performance at larger length scales which makes it important to understand not only the phenomena and the behavior at the Nano/molecular level but also how these changes build up to the macro scale level. At the Nanoscale level, Computational molecular dynamics simulations (MD) are a more effective alternative testing method, especially regarding destructive testing, as they are considered the most viable approach at the Nanoscale level.

1.1 Cement products

At the Nano/molecular scale level, there are two phases of cementitious materials: un-hydrated or dry cement constituents, and hydrated cement products. Cement powder in its raw material form consists of un-hydrated constituents, while the hydrated constituents are formed during the hydration process of the water-cement mixture. For un-hydrated cement constituents, the most common cement form are Tri-

Calcium and Di-Calcium silicate. For hydrated cement products, hydration of cement is a chemical reaction between cement compounds and water that are mixed to form the cement paste. This reaction causes hardening of the cement resulting in hydrated cement constituents that affect strength to cement paste. Hydration is a very complicated process and produces complex hydrated material constituents. The most critical hydrated cement products are Calcium Hydroxide (CH) and Calcium Silicate Hydrate (CSH). Table 1 shows some examples of un-hydrated and hydrated cement products along with their chemical formulas and notation (ACI education bulletin, 2001).

Table 1 Portland cement compounds, chemical Formulas, and shorthand notations

Name	Chemical formula	Shorthand notation
Tri-Calcium silicate (alite)	$3CaO.SiO_2$	C_3S
Di-calcium silicate (belite)	$2CaO.SiO_2$	C_2S
Calcium hydroxide	Ca(OH)2 or CaO.H2O	CH
Calcium silicate hydrate	2(CaO).SiO2.0.9-	CSH

1.2 Cement molecular structure

The molecular structure represents the nanometer/molecular scale features of the material system. In the present work with an emphasis on nanometer material scale, the focuses for un-hydrated cement constituents are on C_3S and C_2S. The focus of hydrated cement is on CH and C-S-H gel.

There are a few proposed crystalline structures of tri-calcium silicate C_3S, for example (Urabe, 1999) (Golovastikov, 1975). In the present work, Golovastikov's triclinic C_3S crystalline structure with cell size (11.67x14.24x13.72) Å, and angles (α = 105.5, β = 94.33, γ = 90) was employed. The crystalline structure of Di-calcium silicate (belite) C_2S followed the proposed crystalline structure by (Mideley, 1952) with cell size (5.48x6.76x9.28) Å, and angles (α = 90, β = 94.33, γ = 90).

Concerning hydrated cement products (Harutyunyan, 2009) investigated and studied the early growth of calcium hydroxide (CH) crystal using X-ray transmission microscopy imaging to evaluate crystalline growth rate by analyzing hydration process images. CH crystalline structure used in the present work built upon Harutynuyan's investigations, and proposed by (Henderson, 1962) was obtained from the American Mineralogist Crystalline Structure Database (A.M.C.S). CH crystalline structure with cell size (3.59x3.59x4.9) Å, and angles (α = 90, β = 90, γ = 120).

CSH gel is a very complicated hydration product. The complexity of this structure is due to the different mix proportions of calcium, silicon, and water leading to distinct chemical formulas with corresponding structures. Even now, the molecular structure of CSH is debatable, and the consensus of the correct molecular / nanoscale representation does not exist although there have been several studies to find a close molecular structure representation. In this research, Jennite crystal structure by Bonaccorsi et al. (Bonaccorsi, 2004) was used as a representation for CSH. They analyzed the triclinic crystalline structure of Jennite using X-ray diffraction. In this structure, the triclinic refined unit cell were (a = 10.576, b = 7.265, c = 10.931) Å, α = 101.30, γ = 109.65, β = 96.98. The crystalline chemical formula of Jennite is $Ca_9Si_6O_{18}(OH)_6.8H_2O$. They concluded that Jennite transforms to metajennite at 70-90^oC by losing four water molecules. Figure 1 shows molecular structures for bot hydrated and un-hydrated cement products at the nanoscale level.

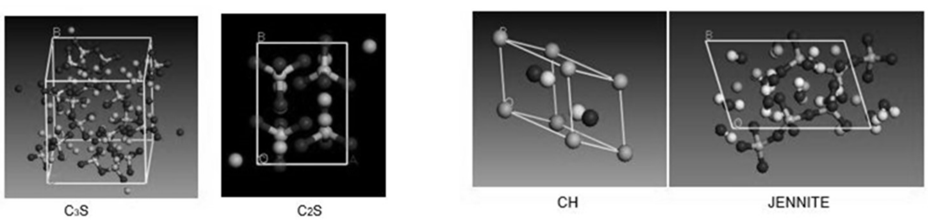

Figure 1 Cement products molecular structures

1.3 Computational modeling

Computational modeling provides a potentially useful method to study the behavior of cementitious materials at the molecular level. Computational modeling has now become the third method of investigation in several sciences and engineering disciplines. Computational models along with both experimental investigation and theoretical studies are useful when conducting experiments is cost prohibitive and impractical. Computational Materials Science (CMS) is the fastest growing area in materials research because of the availability of increased computational power, advances in physics and chemistry, and economic viability (Dolado, 2011). CMS approaches based on robust modeling representations are needed for material development and understanding their characteristics.

Researchers are now taking advantage of the computational modeling capability to simulate, predict, and study properties of materials. The molecular material configuration is an essential factor in these CMS modeling studies, and the majority of literature are concentrating on model creation rather than designing new materials. Model creation promotes rule setting regarding accurate model representation of the material structure. It also facilitates analysis of existing materials toward the theoretical development of new materials, and their structures, with the desired properties.

Current computational power is enabling extensive analysis to be performed at the Nanoscale level even for complex, large molecular material systems. The challenge is to create accurate computational models and methods, which can represent the cementitious materials molecular structures, and predict the mechanical properties of cement at the Nanoscale (Dolado, 2011).

The possible material configurations at this scale are at the atomic and molecular level, and the corresponding molecular dynamics modeling methods are applicable. The individual electron degrees of freedom are simplified. The degrees of freedom include the potential energy function via electrostatic energy terms that govern the interaction between the atomic nuclei. Current computational power allows solving larger models at the Nanoscale level as molecular scale models neglect movement of individual electrons computationally simpler to solve than at quantum scale models

The computational methodology employed at such molecular scales is molecular dynamics MD modeling methodology that is based on Newton equation of motion describing the movement of individual atoms in a molecular material system. The general form of this equation is given by

$$F_i = m_i a_i = m_i \frac{dv_i}{dt} = m_i \frac{d^2 r_i}{dt^2}$$

where:
m_i is atom mass, v_i is atom velocity, r_i is atom position, and F_i is the force acting on a particular atom.

However, the discrete differential equations are applied for each atom, the force term that is defined as the gradient of the potential energy includes the effect of all of the atoms, bonded and non-bonded interactions in the molecular structure. The challenge is to create accurate computational models that represent the material structure as well as their associated energy. This energy accounts for all possible bonded and non-bonded atom movements as well as the electrical charges associated with the molecular system.

1.4 Mechanical properties at molecular scale level

The current literature for predicting cement mechanical properties, using MD simulations, such as:

Al-Ostaz et al. (A-Ostaz, 2008), used Molecular Dynamics (MD) simulations to predict the mechanical properties of hydrated cement products. The most important products by volume were Calcium Silicate Hydrate (CSH) and Calcium Hydroxide (CH). In their work, CSH, which is about 50-60% of hydrated cement volume, was represented by two different structures: Jennite and Tobermorite 14Å crystals. CH is about

20-25 percent of hydrated cement solid volume was represented by Portlandite crystal. The mechanical properties such as elastic, shear, and bulk modulus were calculated using Materials Studio Accelrys MD modeling analysis code and compared with available values from the literature (Velez, 2001), (Constantinides, 2004).

Weidong et al. (Weidong, 2011), performed MD simulations to predict the mechanical properties of major Portland cement compounds. Portland cement compounds used in their study were C_3S, C_2S, and C_3A. COMPASS, Universal force field (UFF), and Dreiding force fields were employed and compared in their MD analysis. A combination of different force fields and different cell sizes were investigated and, the results were compared with the data from nanoindentation experiments of cement samples. Their results demonstrated that the choice of the force field has a significant effect while the size of the supercell has a minimal impact on predicted mechanical properties. They also concluded that the COMPASS and Forcite Plus force fields as defined within the Materials Studio Accelrys were suitable for C_2S and C_3S while Dreiding force field was stated to be more appropriate for C_3A.

Hall et al. (Hall, 2010), used MD to understand the mechanical behavior of cement paste. They used CSH low and high-density molecular structures. They used MD to model the tensile deformation and obtain stress-strain curve model. Also, they estimated elastic modulus for two CSH models: CSH with continuous silicate chains and CSH with dimer silicate chains. Their reported values were 96 GPa for continuous silicate chains and 70 GPa for dimer silicate chains.

A review of the literature on the MD predicted mechanical properties of cementitious materials reveals interest has been limited to atmospheric pressure condition. In the present work, the prediction of mechanical properties was expanded to higher thermodynamic pressure state conditions. MD provides an effective methodology to computationally predict the expected property changes under different thermodynamic state conditions.

2. Computational modeling parameters

A conventional method used at Nano/molecular scale of materials is molecular dynamics (MD). MD is a computational method for solving dynamic Newton's equation of motion of interacting atoms and molecules over time. MD method was initially developed in the late 1950s and early 1960s by (Alder, 1959). Over the years, MD has been employed for predicting the properties of different material systems based on their molecular structures. Also, several MD analysis coding developments have evolved resulting in several open source and commercial MD analysis codes such as GROMACS, CHARMM, LAMMPS, and Accelrys. These codes with varying features, force fields apply to several material systems and MD analysis. Accelrys Material Studio, a commercial MD code with a variety of modules and available force fields with a Graphical User Interface (GUI), was used in the present study (Accelrys).The MD simulation model has several parameters that control the accuracy of the results. These parameters are super cell size, molecular tool, energy minimization, force field, MD ensemble, temperature and temperature control method, pressure and pressure control method, time step, dynamics time, cutoff distance and periodic boundary conditions.

2.1 Supercell size

Different cell size structures were tested to study the effect of unit cell size on the mechanical properties. One unit cell, eight unit cells, and twenty-seven unit cell.

2.2 Molecular tool

Accelrys material studio has some molecular dynamics analysis tools; these tools are Forcite, Discover, and Amorphous. In this study, based on the literature, the Discover tool was used.

2.3 Energy minimization

The purpose of energy minimization is to find the stable molecular structure configuration, which corresponds to the lowest energy for the molecular system. There are several methods for detecting the global minimum energy configuration in a static MD analysis. Some standard methods that can be used in static minimization and available in many MD analysis codes are steepest descents method, conjugate gradient method, Newton-Raphson method, and the Simplex method.

Smart minimization method implemented within the MD analysis code Materials Studio – Accelrys uses a combination of the Gradient and Hessian methods. Minimization algorithms are set up for small molecular systems with less than 200 atoms, to begin with, the steepest descent method, followed by the conjugate gradient method and end with a Newton-Raphson method. Molecular systems bigger than 200 atoms start with the steepest descent method followed by the conjugate gradient method.

2.4 Force field

The Force field (FF) is a collective mathematical representation of total potential energy for a molecular system. The coefficients in the mathematical expressions vary for different molecular types based on the material atoms involved. The FF parameters contributing to the various energy terms in the potential energy can be determined either from experiments or from higher levels quantum mechanics calculations. Recently, some force fields are used in several MD analysis codes. Examples of these force fields are MM3, MM4, DREIDING, SHARP, VALBON, UFF, CFF93, AMBER, CHARMM, OPLS, and MMFF. In general, force fields employed in MD analysis follow three different directions. For cementitious materials, with the unhydrated and hydrated molecular structures showing crystalline / semi-crystalline structure, COMPASS force field has been used. The functional form of the COMPASS (Condensed-phase Optimized Molecular Potentials for Atomistic Simulation Studies) contains three significant terms: bonded terms, non-bonded terms, and cross terms (Sun, 1998).

2.5 MD ensemble

In MD analysis, Ensemble is a collection of molecular configurations over time satisfying the same macroscopic or thermodynamic properties such as the number of atoms (N), pressure (P), temperature (T), volume (V), energy (E), and enthalpy (H). Several statistical ensembles can be generated during the dynamics analysis, and material properties can be calculated from these ensembles under the common thermodynamic state conditions. The most common ensembles used in MD analysis are (NVE) Micro-canonical ensemble, (NVT) Canonical ensemble, (NPT) Isobaric-Isothermal ensemble, and (NPH) Isobaric-Isenthalpic ensemble. The number of atoms is fixed for all of these ensembles. NPT and NPH are usually used for periodic systems because in nonperiodic systems, the volume is undefined (Accelrys). NVE is a fixed number of atoms, fixed volume, and fixed energy. NVE is not recommended for equilibration, but it is useful for exploring constant energy configuration. In NVE there is no control on pressure or temperature (Accelrys). NVT is a fixed number of atoms, fixed volume, and fixed temperature. NVT is an excellent choice when pressure is not a significant factor. NPT is a fixed number of atoms, fixed pressure, and fixed temperature. NPT is a good choice when the pressure and the temperature need to be controlled during the MD analysis. NPH is a fixed number of atoms, fixed pressure, and fixed enthalpy. NPH can be used during equilibration phase of simulation with no temperature control in this ensemble.

2.6 Temperature and temperature control method

The temperature in MD is a kinetic quantity depending on the atom velocities. Temperature thermodynamic state thus requires several temperature control methods in an MD analysis. Several temperature control methods or thermostats are defined in MD codes and used in the study. Some of these methods are Velocity scaling, Berendsen, Anderson, and Nose-Hover.

2.7 Pressure and pressure control method

Pressure control methods are used to achieve the target statistical ensembles thermodynamic pressure states. Examples of the pressure control methods that are available for analysis selection in Materials Studio Accelrys are Parrinello, Berendsen, and Anderson.

2.8 Time step

The correct choice of the time step value will lead to stable and accurate results. In MD analysis practice the time step should be approximately one-tenth of the shortest period of motion of the atoms. Since the vibration range of the atoms in the solid lattice is 10^{-14}s, a value of 10^{-15}s (1 fs) will be appropriate as a time step (Lee, 2012). Though the smaller, the time step the more accurate the results but increases the computational requirements.

2.9 Dynamics time

If dynamics time is too short, the system will not reach a relaxed state. Therefore, the results will not be reliable, and not all possible system configurations are accounted. If MD runtime is too long, there is also the possibility of numerical error accumulation. The range of the MD run is from 10^3 to10^8 time steps, which are from a few Picoseconds to a few hundred Nanoseconds ($10^{-9}s$) (Lee, 2012). The correct dynamic analysis duration varies across different material systems, and several parametric studies are conducted to establish accepted time duration in any MD analysis.

2.10 Cutoff distance

During the MD run, most of the computation time involved is to compute the potentials. By using cutoff distance, the long distance interactions become irrelevant. The cutoff distance is a radius of a sphere around each atom where the non-bond interactions outside this sphere are neglected for that atom. This parameter is defined by the user and can vary for different material systems. Cutoff distance should be smaller than half the unit cell dimension. Further details on the cutoff distances within the context of Materials Studio Accelrys can be found in reference (Lee, 2012).

2.11 Periodic boundary conditions

The use of PBC enables the use of smaller molecular configurations representing a bulk system in MD analysis for the prediction of properties. The relative volume element (RVE) does not feel the existence of the boundary, which means the number of atoms inside the central box, stays the same. The simulations affect only the atoms in the central cell. If one atom moves from the central cell, another atom from the other side moves in and replaces it. This movement keeps the number of atoms inside the central box constant (Lee, 2012)

3. Results

Several dynamic simulations models were done for un-hydrated cement products C2S and C3S, hydrated cement products Calcium hydroxide CH and Calcium Silicate Hydrate CSH Jennite representation. These models were to predict the mechanical properties such as Elastic modulus, Bulk modulus, Shear modulus and Poisson's ratio. These models were predicting the mechanical properties at atmospheric pressure, the effect of cell size on the mechanical properties, the impact of different dynamic times and the effect of varying pressure values.

3.1 Mechanical properties at atmospheric pressure

The following model parameters including Super cell size: one unit cell; Molecular tool: discover; Energy minimization: Smart minimization; Force field: campus; MD ensemble: NPT; Temperature: 298K (25°C); Temperature control method: Anderson or Nose; Pressure: 0.0001 GPa, Pressure control method: Parrinello or Berendsen; Time step: 1 femtosecond; Dynamics time: 100 Picosecond, Cutoff distance: 12.5 nm and PBC was on when predicting the mechanical properties at the atmospheric pressure. Table 2 shows the predicted values, for C_3S, C_2S, CH, and CSH Jennite, at atmospheric pressure.

Table 2 Mechanical properties of atmospheric pressure

Properties	C_3S	C_2S	CH	Jennite
Elastic modulus	164	277	227	69
Bulk modulus	177	168	110	70
Shear modulus	61	113	98	26
Poisson's ratio	0.35	0.23	0.15	0.34

Mechanical property predictions from the current MD analysis are in excellent correlation with prior MD analysis results (Weidong, 2011) at atmospheric pressures. The results are also reasonably comparable to the experimental values from Nano-indentation experiments, which are generally at a larger material scale than the MD analysis, and other reported data based on resonance frequency tests at microscale level (Boumiz, 1997) (Haecker, 2005) (Velez, 2001).

3.2 The effect different cell sizes

Another simulation model was done to study the influence of different molecular cell sizes on the predicted mechanical properties. This model used the same parameters as the atmospheric model except for the cell size. Three different cell sizes were used V1, V2, and V3. V1 was constructed from one unit cell. V2 was constructed by replicating the unit cell twice in all three directions (2x2x2) 8 unit cells, and finally V3 was constructed by replicating the unit cell three times in all three directions (3x3x3) 27 unit cells. There is no significant difference in Poisson's ratio results except for CH structure. Figure 2 shows the effect of different cell sizes on Elastic, Bulk and Shear Modulus.

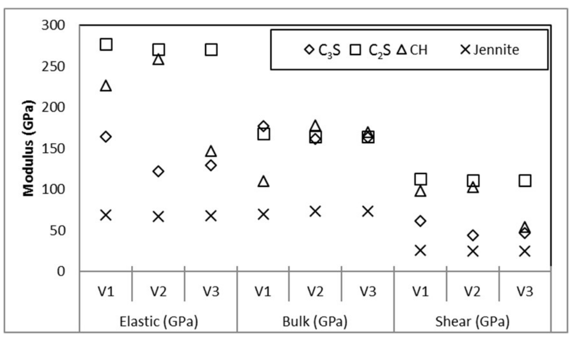

Figure 2 Effect of different cell sizes

3.3 The effect of different dynamic times

Another simulation model was done to compare the predicted mechanical properties using different simulation time durations. This model has the same parameters as the atmospheric pressure model but three different duration times were used. These duration times were 100 Pico seconds (PS), 200PS and

300 PS. There is no significant difference in Poisson's ratio results except for CH structure. Figure 3 shows the effect of different dynamics duration times.

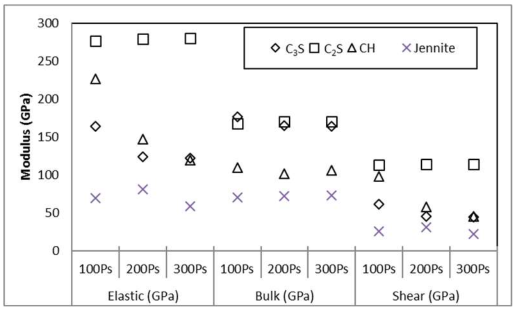

Figure 3 Effect of different dynamics time

3.4 The effect of varying pressure values

Finally, series of simulation models to study the effect of varying pressure values on the mechanical properties of C_3S, C_2S, Ch, and CSH Jennite. These models had the same parameters as the atmospheric model, but the pressure values were changing from atmospheric (0.0001 GPa) to (1 GPa). Figure 4 shows the results for using different pressure values.

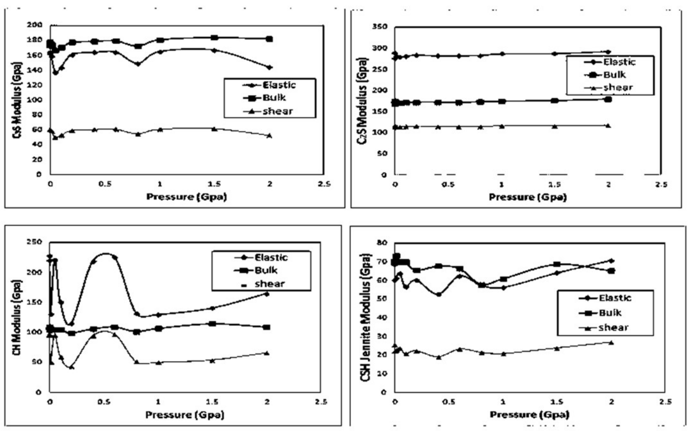

Figure 4 Results for different pressure values

4. Conclusion

Molecular Dynamics (MD) is a viable method for prediction of mechanical properties of various cementitious materials. MD results at atmospheric pressure showed excellent agreement with previous MD simulation results.

Cell size and dynamic time have a significant effect on the predicted properties of Calcium Hydroxide (CH), a slight effect on the mechanical properties of Tri-Calcium Silicate (C_3S), CSH Jennite, and no significant effect on the mechanical properties of Di-Calcium Silicate (C_2S).

The properties predicted using MD are significantly higher than the experimental results, because of the use of ideal structure at the molecular scale level.

The predicted mechanical properties of both un-hydrated and hydrated cement are affected by thermodynamic pressure. The effect seems to be more noticeable for hydrated products.

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A Novel Approach to Supplier Assessment Process for Manufacturing Companies with Existing Suppliers

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Abstract

In the global supply chain, appropriate and sustainable suppliers play a vital role in supply chain development and feasibility. In any big organization with a large number of suppliers, it is necessary to divide suppliers based on their track-record for supplier development program and new product development. The performance of any organization to a large extent depends on their suppliers' performance. Hence, well evaluated selection criteria and, decision-making models which lead to improved supplier assessment and development are necessary. In this paper, the SCOR® performance evaluation approach and ISO standards are used to determine selection criteria for better utilization of supplier assessment by using a hybrid model of Analytic Hierarchy Problem (AHP) and Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS). AHP has been used to determine the global weightage of criteria that helps TOPSIS to get the suppliers' performance score. The qualitative criteria are taken into consideration for the supplier assessment process. A case study of a manufacturing firm with five suppliers has been used to demonstrate the result of the hybrid model.

1. Introduction

In today's world of global supply chain, every industry is facing increasing challenges to reduce total cost of raw-materials, to increase the bottom line of the income statement and, to maintain the quality of the final product while they remain competitive in the market. People in industries are required to take advantages of optimization of the supply chain process. They also need to improve the performance of the whole supply chain with great customer satisfaction and lower lead time starting from the suppliers' level. As Gonzalez et. al. (2004) mentioned for manufacturing businesses, there are numerous variables that are critical for success of any company which are: Suppliers, Quality and Manufacturing.

In a manufacturing firm, purchased goods and services constitute 70% of the total cost and, in high tech industries, materials and services covers 80% of total cost (Ghodsypour, et al, 2001). Manufacturing industries decide to manufacture a product in house, acquire from the contract manufacturers (CM) or provide the contracts and, from suppliers based on the customer requirements and expenses of the product before (i.e. set up cost, labor cost) and after production (i.e. warranties). The choice of suppliers is a key decision that every company needs to make based on some key parameters from the potential list of suppliers while aiming to reduce the total cost of ordering.

Supplier relationship management is a strategic approach for managing supplier behavior and relationships that encompass innovation, risk and cost, quality and, responsiveness (Schuh, et al, 2014). The evaluation of suppliers' performance happens at two distinct moments of the supplier management process. These are supplier the selection phase and the supplier performance assessment phase (Lima-Junior, et al, 2016).

1.1. Supplier Assessment

Supplier Assessment is a management practice for organizing suppliers aimed at improving performance and capability to fulfill the supply needs based on the production planning needs of a manufacturing firm (Lima-Junior, et al, 2016). It is a multi-criteria decision-making problem based on a wide range of factors. Most manufacturing companies evaluate the suppliers' performance based on the cost, quality and delivery alone from the customer's point of view and quality standards (Ho, W., et al, 2010). The parameters are decided by the group of decision makers based on the characteristics and requirements of the final product.

As part of the supplier-relationship management process, a supplier assessment process is performed periodically in which suppliers are grouped based on their performance and the criticality of the product. The quality and criticality of the product are crucial factors from the end customers' point of view. The core difference between the supplier assessment and supplier selection process is the data that can be gathered as a part of the decision-making process. Apart from the suppliers' data, the evaluation criteria also play an important role for the assessment process as more parameters can give a better result for the supplier assessment process compared to the normal supplier selection process even though more factors increases the complexity of the decision process.

In the literature review, most of the authors considered supplier selection processes based on qualitative and quantitative criteria. Qualitative criteria are those parameters that use linguistics variables for converting human perception for evaluation to numbers in order to get a supplier performance score. The score is used for supplier development programs or for the order allocation processes. Quantitative criteria are those which are in terms of numbers and can be used for the optimization process for cost reduction, quality maximization and lead time reduction in the order allocation processes.

The objective of this research is to investigate the supplier performance process for already available suppliers to restructure the organization based on the previous history in all parameters which contain the qualitative and the quantitative criteria. The primary motivation of this research is to get supplier performance based on qualitative criteria. The qualitative criteria include social, economic and, environmental criteria for the supplier development program.

The sequence of the research is as follows: Section 2 contains the detailed information about the relevant literature for the current research in different areas including decision making models, fuzzy environment scenarios, single and multi-time period scenarios. Section 3 specifies the problem description and assumptions that are made for this research and methodology for the solution of the supplier assessment problem. Section 4 represents the case study to validate the methodology. Conclusions and future research are covered in Section 5.

2. Literature Review

Many industrial practitioners and academic researchers have started to work on supplier selection and assessment decision making modes. Hamdan et al. (2017) presented green supplier selection and order optimization by using an integrated approach of fuzzy TOPSIS and AHP and the branch cut algorithm. Jadidi et al. (2014) developed a Multi-Objective Optimization Problem (MOOP) for minimization of cost, rejects and lead times. Since, the sustainability concept is important for SCM; social, economic and environmental criteria are considered for one of the objectives for order allocation (Kannan, et al, 2013; Nourmohamadi Shalke, et al, 2017; Kumar et al, 2017).

Babić et al. (2014) proposed multi-product vendor selection with volume discounts by using fuzzy set theory. In their study, quality and reliability are considered as core factors for the model and parameters were aggregated by using the Simple Additive Weighting method (SAW). Demirtas et al. (2008) considered 14 criteria divided into four clusters which are Benefits, Opportunities, Costs and Risk (BOCR) by considering three decision maker's preferences. As production planning was done based on customer demand, Trivedi et al. (2017) focused more on demand of finished goods, Bill of Materials (BOM), machine capacity and supplier capacity in the model for order allocation. Mafakheri et al. (2011) considered total cost of purchase (TCP) and total value of purchase (TVP) as an objective function with 21 sub-criteria divided into 4 main criteria which are price performance, delivery performance, and environmental performance and quality.

Due to uncertainty in human perception of thinking, fuzzy set theory has been used instead of crisp numbers in the decision-making process. Hence, trapezoidal and triangular fuzzy numbers have been used to deal with quantitative and qualitative criteria for supplier selection and evaluation (Chen, et al, ,2006; Gupta, et al, 2016) proposed weighted possibilistic programming approach in a fuzzy environment for sustainable supplier selection and order allocation. Amin et al. (2011) considered the fuzzy logic and triangular number with integration of SWOT analysis for multi-product and single time period. They divided supplier selection criteria as internal and external for SWOT analysis. Boran et al. (2009) used Intuitionistic Fuzzy Weighted Averaging (IFWA) for aggregating decision maker's opinions in TOPSIS for rating the importance of the criteria.

Many researchers and academicians have started focusing on an artificial neural network approach for the supplier selection problem. GuNeri et al. (2011) presented Adaptive Neuro-Fuzzy Inference System (ANFIS) model which has three components which include a rule base, a database, and a reasoning mechanism. Kar et al. (2015) considered the extension of a neural network for classification and discriminant analysis for a supplier base rationalization into highly suitable suppliers and less suitable suppliers by using back propagation algorithms. Kuo, R. J. et al. (2010) demonstrated an integrated model of Artificial Neural Network and Multi-Attribute Decision Analysis (MADA) for green supplier selection because of raising awareness in environmental problem and sustainability development in industries.

Lima-Junior et al. (2016) stated that the evaluation of suppliers can be done at two different phases in the supply chain: supplier selection, and the supplier development and evaluation phase. They classified suppliers into four groups based on the score obtained by using a fuzzy TOPSIS model. Ho, W. et al. (2010) presented a comprehensive literature review for supplier evaluation and selection. They divided the supplier selection decision-making model into four main aspects: Decision problem, decision makers, decision environments, and decision approach. The decision-making model have been used as individual stand-alone methods and as hybrid models (Wu, et al, 2009) based on the application. In supplier selection, most of the researchers have focused on the individual decision-making model with fuzzy sets (Guneri, et al, 2009). Sanayei et al. (2010) illustrated the VIKOR method to select the suitable suppliers with conflicting and non-commensurable criteria. Shyur et al. (2006) applied the Nominal Group Thinking (NGT) with interdependence techniques to identify proper criteria for strategic supplier selection in which weights of each individual criteria are decided later by using the Analytic Network Process (ANP).

Supplier selection and assessment has achieved significant attention for producing a sustainable product in the supply chain and has a significant impact on the total cost of final product. In the supplier assessment problems, qualitative criteria have been decided based on ISO 9000: 2015 and SCOR (Supply Chain Operations Reference). The objective of this paper is to develop a model for supplier assessment by using a multiple criteria decision methodology to determine supplier performance based on data for current suppliers, which in turn can be used to restructure the supply chain and for the supplier development program and new product development.

3. Methodology

A qualitative approach to supplier assessment is used to get supplier performance in different criteria based on their past performance. We have used a multi-criteria hybrid approach of TOPSIS (Techniques for Order Preference by Similarity to Ideal Solutions) and AHP (Analytic Hierarchy Process) to evaluate suppliers in different criteria. In this research, to come up with the hierarchy for assessment criteria, the ISO 9000: 2015 quality management system standards for supplier quality and, Supply Chain Operation Reference (SCOR®) metrics were considered for sustainable evaluation of suppliers.

Figure 1 shows the hierarchical structure of criteria and its sub criteria. Table 1 shows the definition of each parameter.

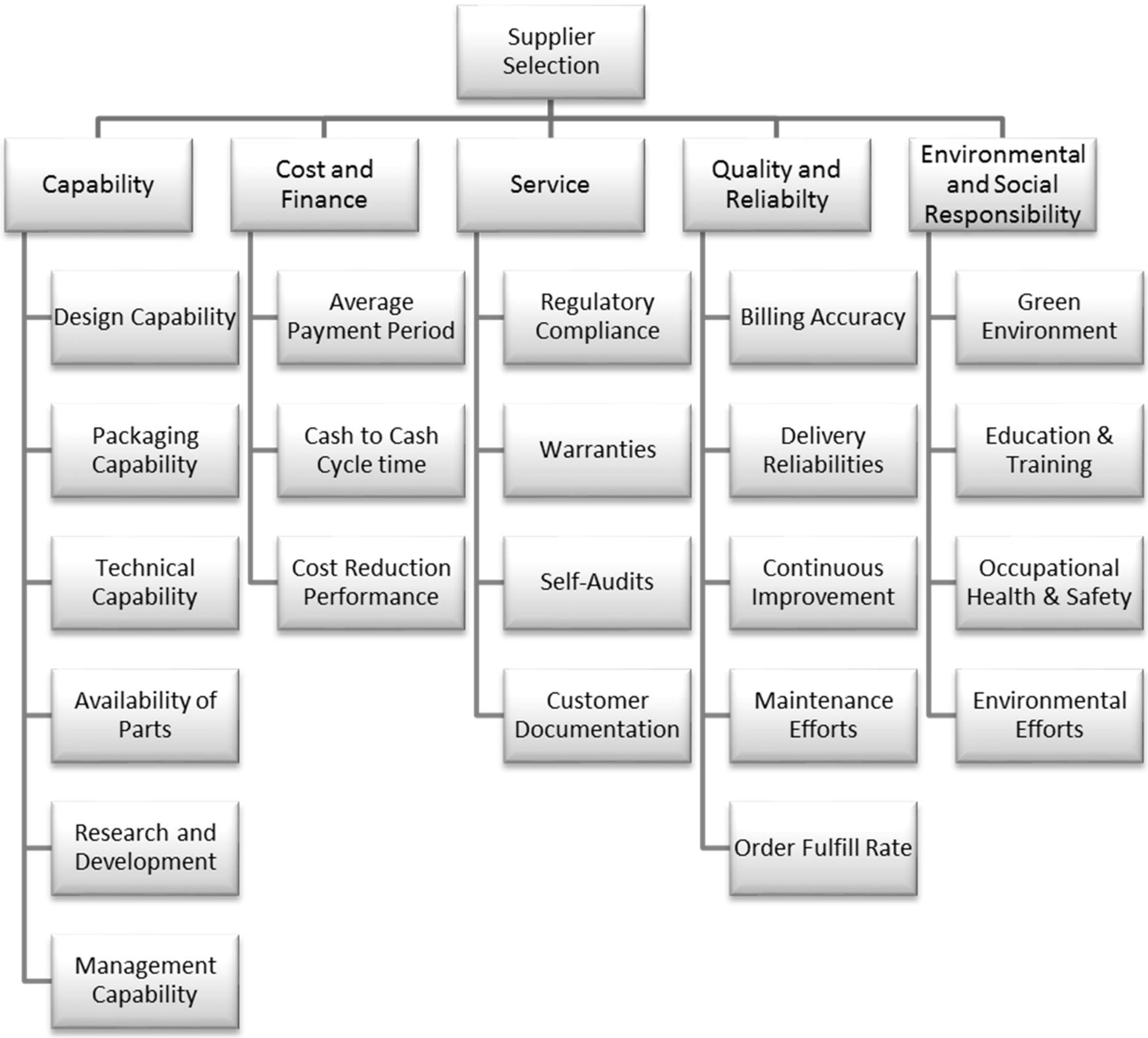

Figure 1. Hierarchy for Supplier Assessment parameters

3.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process is a decision-making method for dealing with the tangible and intangible parameters when prioritization of factors and conflict resolution must be considered (Saaty, 1980). It uses a derived ratio scale from discrete as well as continuous paired comparisons in hierarchic problems taken from the Likert scale reflecting the relative strength of preferences. AHP consists of three primary principles which includes decomposition, comparative judgement and, priority synthesis. The steps that AHP uses for the hierarchical structure is as given below.

Table 1: Definitions for each parameter

Criteria	Acronym	Sub-criteria	Definition
Capability	C1	Management Capability	Degree of importance given to complaints and quality function in organization
	C2	Design Capability	Capability of developing new designs and speed of development
	C3	Packaging Capability	Percentage of damaged packages during delivery
	C4	Technical Capability	Supplier's capability to develop new product design and response for product development
	C5	Availability of Parts	Right action of the supplier in an unusual event experienced about orders and how supplier meets the company's expectation
	C6	Research and Development	Supplier should have a strong R&D to incorporate innovation to adapt with the present market turbulence
Quality and Reliability	QR1	Billing Accuracy	Percentage of bills that are error-free
	QR2	Delivery Reliability	Percentage of items that arrive on or before the requested ship date
	QR3	Continuous Improvement	The application of process improvement activities carried over period of month
	QR4	Maintenance Efforts	The amount of time taken by suppliers for rejected parts that sent back to them for maintenance
	QR5	Order Fulfill Rate	Percentage of customer's order that are filled on the first shipment
Service	S1	Regulatory Compliance	Supplier's adherence to regulation and specification of products with company's standards (ISO 0r AS)
	S2	Warranties	Existence of warranties and claim policies provided by supplier
	S3	Self-Audits	The formal examination of supplier's financial situation over year
	S4	Customer Documentation	Orderly preparation of delivery controls documents and bills
Environment and Social Responsibility	ESR1	Green Environment	Supplier's performance on design of products for reuse, recycle and reduce consumption of energy
	ESR2	Education and Training	Supplier's profile on education and training practices at the workplace by considering sustainability
	ESR3	Occupational Health and Safety	Labor Relations, human rights and interests of employee with safe and healthy working environment to prevent accidents
	ESR4	Environmental Efforts	Certification requirement of environment management system (OSHA or EHS)
Cost and Finance	CF1	Average Payment Period	Average time from receipt of materials and payment for those materials
	CF2	Cash to Cash Cycle Time	Number of days between paying for materials and paid for product
	CF3	Cost Reduction Performance	Compliance of the process taken from the supplier with average market price with other competitors

Step 1: A hierarchy for the objective function and its evaluation criteria are decided by the group decision makers. For this case, 5 criteria and 22 sub-criteria are considered for the qualitative analysis.
Step 2: The pairwise comparison for each parameters and sub-criteria are considered in matrix form. Decision makers provide judgements about the relative importance with respect to the overall goal.
Step 3: The normalized priority vector across the rows can be obtained by Equation (1) where i shows the rows and j indicates the columns of the matrices.

$$\mathbf{k_{ij} = m_{ij} / \sum_{i=1}^{n} m_{ij}} \tag{1}$$

Step 4: Establish the global priorities called "Normalized priority weights" based on pairwise comparison. The importance weights of the criteria can be calculated using Equation (2).

$$\mathbf{W_i = \sum_{j=1}^{n} k_{ij} / n} \tag{2}$$

AHP has been used effectively to measure relative effect of parameters affecting possible outcomes, and by doing so predicts the outcomes based on evaluating alternative courses of action. As Saaty (1980) mentioned, the largest Eigen value is always equivalent to the number of comparisons made in a reciprocal matrix. The consistency index can be calculated by using given Equation (3).

$$\mathbf{CI = \frac{\lambda max - n}{n-1}} \tag{3}$$

Saaty (1980) proposed to compare the consistency index with the random consistency index (RI) as shown in Table 2 for a matrix with a sample size of 500.

Table 2. Random Consistency index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Consistency Ratio is the comparison between consistency index (CI) and the Random consistency index (RI) as given below in Equation (4).

$$\mathbf{Consistency\ Ratio\ (CR) = \frac{CI}{RI}} \tag{4}$$

The consistency value can be computed by comparing principal Eigen value lambda (max) and the Eigen vector lambda. A CR (consistency Ratio) should be less than 10% to interpret the result (Saaty, 1989).

3.2. Techniques of Order Preference by Similarity of Ideal Solutions (TOPSIS)

One of the **moderate** and convenient techniques for multiple criteria decision making was developed by Hwang and Yoon in 1981. This method known as Techniques of Order Preference by Similarity of Ideal Solutions (TOPSIS), deals with the distance of linguistic variables of the alternatives from the positive ideal solution (the one which has the best value for all attributes considered) and the negative ideal solution (the one which has the worst value for all attributes considered). Due to limitations of AHP in many pairwise comparison complexity and compensation between good scores on some criteria and bad scores on other criteria (Ho, W. et al., 2010), we have proposed the TOPSIS algorithm to get supplier performance assessment scores. TOPSIS works based on the score of each alternative with respect to each criterion if we have 'm' alternatives and 'n' attribute/criteria**.** The steps of the general TOPSIS algorithm process are given below.

Step 1: Construct a normalized decision matrix ($\mathbf{r_{ij}}$). This step transforms linguistic variables into numbers for different attributes which allows comparison between two non-dimensional criteria. The normalized decision matrix can be described as shown in Equation (5).

$$\mathbf{r_{ij} = f_{ij} / \sqrt{\sum_{i=1}^{n} f^2_{ij}}} \tag{5}$$

2.

Step 2: Construct a weighted normalized decision matrix (**V_{ij}**) shown in Equation (6). The weights of each criterion and sub-criteria has been decided by using Analytic Hierarchy Process (AHP).

$$\mathbf{V = [V_{ij}]_{m\times n}} \text{ Where } \mathbf{i = 1,2,3,\ldots,m} \text{ and } \mathbf{j = 1,2,3,,n} \quad (6)$$

$$\text{and } \mathbf{V_{ij} = r_{ij} \times W_j}$$

Step 3: Compute the positive ideal solution and negative ideal solutions from the normalized decision matrix for each criteria and sub-criteria. It can be calculated using Equation 6 and 7:

Positive ideal solution A^+ $= (V_1^+, V_2^+, \ldots, V_n^+) = (\max(V_{ij}) \text{ if } j \varepsilon J, \min(V_{ij}) \text{ if } j \varepsilon J')$ (7)

Negative ideal solution A^- $= (V_1^-, V_2^-, \ldots, V_n^-) = (\min(V_{ij}) \text{ if } j \varepsilon J, \max(V_{ij}) \text{ if } j \varepsilon J')$ (8)

Where **i = 1, 2, 3,…, m** and **j = 1,2,3,…,n**

Step 4: Estimate the distance of each alternative from the positive ideal solutions and negative ideal solutions. The distance measures can be obtained by applying Euclidean distance theory by the given Equations 8 and 9.

$$\mathbf{d_i^+ = \{ \textstyle\sum_{j=1}^{n} (v_{ij} - v_j^+)^2 \}}, \ i = 1,2,\ldots,m \quad (9)$$

$$\mathbf{d_i^- = \{ \textstyle\sum_{j=1}^{n} (v_{ij} - v_j^-)^2 \}}, \ i = 1,2,\ldots,m \quad (10)$$

Step 5: Calculate the closeness coefficients. It can be calculated as given below by Equation 10. Rank the order preference based on closeness coefficients which can be used as a supplier performance score.

$$\mathbf{CC_i = d_i^- / (d_i^- + d_i^+)}, \quad 0 \le \mathbf{CC_i} \le 1 \quad (11)$$

Table 3 shows the evaluation for rank predilection. The closeness coefficients acquired from TOPSIS of suppliers separately based on all qualitative criteria can be used for supplier development and new product development.

Table 3. Acceptance Criteria

CC(i)	Evaluation
[0,0.2)	Not Recommended
[0.2,0.4)	Recommend with high risk
[0.4,0.6)	Recommend with low risk
[0.6,0.8)	Acceptable
[0.8,1.0)	Accepted and preferred

4. Case Study

This case study is based on a manufacturing firm that is performing an assessment of its existing suppliers. In the case study, a numerical example is presented in which there are five suppliers who provided parts to the firm. The proposed approach is applied to determine suppliers' performance scores which can be used as a development program for suppliers and optimization of the process for ordering cost.

Using the described methodology in Section 3 for the supplier performance score, the decision makers have proceeded with the assessment process as follows:

1) The committee of three decision makers from different departments: quality, manufacturing and, purchasing. The hierarchical structure of the evaluation parameters is shown in Figure 1.
2) A Likert Scale for linguistics variables is generated by decision makers for the importance of criteria and supplier performance score in each criterion as shown in Table 4. The linguistic variables have been kept the same for both AHP and TOPSIS to reduce variability in the final score for supplier assessment.

Table 4: Linguistic variable scale

Linguistics Variables	Numbers
Very Poor	1
poor	2
Medium Poor	4
Fair	5
Medium Good	7
Good	9
Very Good	10

3) Pairwise comparison matrices are developed by all decision makers by the given linguistic variables scale for each criterion and sub-criterion as given in Table 5. For example, *Service (S)* and *Environmental and Social and Responsibility (ESR)* are compared using the question "How important is *Service (S)* when it is compared with *Environmental and Social and Responsibility (ESR)*?" and the answer "between *Fair* and *Medium Good*", to the linguistic Likert scale shown in Table 4. The pairwise comparison matrices may be differing for each decision maker as shown in Table 5.

Table 5. Pairwise comparison matrix of parameters for all decision makers

Decision maker 1

	ESR	S	QR	CF	C
ESR	1	1/6	1/5	1/4	1/3
S	6	1	1/4	1/4	1/5
QR	5	4	1	1/8	1/3
CF	4	4	8	1	1/4
C	3	5	3	4	1

	C1	C2	C3	C4	C5	C6
C1	1	1/4	1/8	1/4	1/9	1/5
C2	4	1	1/6	1/7	1/4	1/5
C3	8	6	1	1/5	1/6	1/4
C4	4	7	5	1	1/7	1/6
C5	9	4	6	7	1	1/8
C6	5	5	4	6	8	1

	QR1	QR2	QR3	QR4	QR5
QR1	1	1/5	1/4	1/7	1/8
QR2	5	1	1/7	1/5	1/4
QR3	4	7	1	1/8	1/6
QR4	7	5	8	1	1/7
QR5	8	4	6	7	1

	S1	S2	S3	S4
S1	1	1/6	1/8	1/7
S2	6	1	1/4	1/6
S3	8	4	1	1/7
S4	7	6	7	1

	ESR1	ESR2	ESR3	ESR4
ESR1	1	1/7	1/5	1/7
ESR2	7	1	1/5	1/3
ESR3	5	5	1	1/3
ESR4	7	3	8	1

	CF1	CF2	CF3
CF1	1	1/8	1/6
CF2	8	1	1/8
CF3	6	8	1

Decision maker 2

	ESR	S	QR	CF	C
ESR	1	1/4	1/4	1/6	1/7
S	4	1	1/7	1/6	1/5
QR	4	7	1	1/3	1/5
CF	6	6	3	1	1/6
C	7	5	5	6	1

	C1	C2	C3	C4	C5	C6
C1	1	1/4	1/5	1/7	1/8	1/4
C2	4	1	1/5	1/3	1/3	1/5
C3	5	5	1	1/5	1/6	1/4
C4	7	3	5	1	1/7	1/6
C5	8	3	6	7	1	1/8
C6	4	5	4	6	8	1

	QR1	QR2	QR3	QR4	QR5
QR1	1	1/6	1/7	1/8	1/5
QR2	6	1	1/6	1/5	1/4
QR3	7	6	1	1/3	1/6
QR4	8	5	3	1	1/7
QR5	5	4	6	7	1

	S1	S2	S3	S4
S1	1	1/5	1/7	1/8
S2	5	1	1/4	1/7
S3	7	4	1	1/8
S4	8	7	8	1

	ESR1	ESR2	ESR3	ESR4
ESR1	1	1/6	1/7	1/8
ESR2	6	1	1/5	1/6
ESR3	7	5	1	1/7
ESR4	8	6	7	1

	CF1	CF2	CF3
CF1	1	1/7	1/5
CF2	7	1	1/6
CF3	5	8	1

Decision maker 3

	ESR	S	QR	CF	C
ESR	1	1/6	1/5	1/4	1/6
S	6	1	1/4	1/4	1/5
QR	5	4	1	1/7	1/6
CF	4	4	7	1	1/4
C	6	5	6	4	1

	C1	C2	C3	C4	C5	C6
C1	1	1/5	1/4	1/6	1/7	1/8
C2	5	1	1/4	1/7	1/4	1/5
C3	4	4	1	1/5	1/6	1/8
C4	6	7	5	1	1/7	1/6
C5	7	4	6	7	1	1/8
C6	8	5	8	6	8	1

	QR1	QR2	QR3	QR4	QR5
QR1	1	1/7	1/4	1/6	1/9
QR2	7	1	1/7	1/5	1/8
QR3	4	7	1	1/3	1/6
QR4	6	5	3	1	1/7
QR5	9	8	6	7	1

	S1	S2	S3	S4
S1	1	1/6	1/8	1/9
S2	6	1	1/4	1/6
S3	8	4	1	1/7
S4	9	6	7	1

	ESR1	ESR2	ESR3	ESR4
ESR1	1	1/8	1/6	1/7
ESR2	8	1	1/5	1/3
ESR3	6	5	1	1/8
ESR4	5	3	8	1

	CF1	CF2	CF3
CF1	1	1/7	1/5
CF2	7	1	1/8
CF3	5	8	1

4) Common pairwise matrices are developed by using the geometric mean for all decision makers' preference shown in Table 6. Geometric mean is less affected by very small or very large values in skewed data rather than the arithmetic mean.

Table 6. Common pairwise matrix of all decision maker's preference

	ESR	S	QR	CF	C
ESR	1	0.191	0.215	0.218	0.199
S	5.241	1	0.207	0.218	0.2
QR	4.642	4.82	1	0.181	0.223
CF	4.579	4.579	5.518	1	0.218
C	5.013	5	4.481	4.579	1

	C1	C2	C3	C4	C5	C6
C1	1	0.232	0.184	0.181	0.126	0.184
C2	4.309	1	0.203	0.189	0.275	0.2
C3	5.429	4.932	1	0.2	0.167	0.198
C4	5.518	5.278	5	1	0.143	0.167
C5	7.958	3.634	6	7	1	0.125
C6	5.429	5	5.04	6	8	1

	QR1	QR2	QR3	QR4	QR5
QR1	1	0.168	0.207	0.144	0.141
QR2	5.944	1	0.15	0.2	0.198
QR3	4.82	6.649	1	0.24	0.167
QR4	6.952	5	4.16	1	0.143
QR5	7.114	5.04	6	7	1

	S1	S2	S3	S4
S1	1	0.177	0.131	0.126
S2	5.646	1	0.25	0.158
S3	7.652	4	1	0.137
S4	7.958	6.316	7.319	1

	ESR1	ESR2	ESR3	ESR4
ESR1	1	0.144	0.168	0.137
ESR2	6.952	1	0.2	0.265
ESR3	5.944	5	1	0.181
ESR4	6.542	3.78	7.652	1

	CF1	CF2	CF3
CF1	1	0.137	0.188
CF2	7.319	1	0.138
CF3	5.313	8	1

5) The normalized principal priority vector is computed by using Equation (1) shown in Section 3 for each criterion and sub-criterion. Table 7 represents the inner-dependence matrix by showing relative importance of the given criteria with respect to the others. A similar computation process is carried out for each matrix.

Table 7. Normalized Principal Priority Vectors

	ESR	S	QR	CF	C
ESR	0.049	0.012	0.019	0.035	0.108
S	0.256	0.064	0.018	0.035	0.109
QR	0.227	0.309	0.088	0.029	0.121
CF	0.224	0.294	0.483	0.161	0.119
C	0.245	0.321	0.392	0.739	0.543

	C1	C2	C3	C4	C5	C6
C1	0.034	0.012	0.011	0.012	0.013	0.098
C2	0.145	0.050	0.012	0.013	0.028	0.107
C3	0.183	0.246	0.057	0.014	0.017	0.106
C4	0.186	0.263	0.287	0.069	0.015	0.089
C5	0.268	0.181	0.344	0.480	0.103	0.067
C6	0.183	0.249	0.289	0.412	0.824	0.534

	QR1	QR2	QR3	QR4	QR5
QR1	0.039	0.009	0.018	0.017	0.085
QR2	0.039	0.009	0.018	0.017	0.085
QR3	0.187	0.372	0.087	0.028	0.101
QR4	0.269	0.280	0.361	0.116	0.087
QR5	0.275	0.282	0.521	0.815	0.607

	ESR1	ESR2	ESR3	ESR4
ESR1	0.049	0.014	0.019	0.086
ESR2	0.340	0.101	0.022	0.167
ESR3	0.291	0.504	0.111	0.115
ESR4	0.320	0.381	0.848	0.632

	S1	S2	S3	S4
S1	0.045	0.015	0.015	0.088
S2	0.254	0.087	0.029	0.111
S3	0.344	0.348	0.115	0.096
S4	0.358	0.550	0.841	0.704

	CF1	CF2	CF3
CF1	0.073	0.015	0.142
CF2	0.537	0.109	0.104
CF3	0.390	0.876	0.754

6) Determine the weightage of each criterion and sub-criterion by using a normalized principle priority vector by using Equation (2). Table 8 shows local and global weightage of each parameter. Multiply all sub-criterion weighting to that of the core criteria respectively to obtain a global weighting of each sub-criteria.

Table 8. Global weightage of each parameter

Main Criteria	Weights of main Criteria	Sub-Criteria	Weights of sub-criteria	Global Weights
Capability	0.448	C1	0.0299	0.0133952
		C2	0.0591	0.0264768
		C3	0.1038	0.0465024
		C4	0.1514	0.0678272
		C5	0.2406	0.1077888
		C6	0.4151	0.1859648
Quality and Reliability	0.1548	QR1	0.0336	0.0052013
		QR2	0.0336	0.0052013
		QR3	0.155	0.023994
		QR4	0.227	0.0351396
		QR5	0.5001	0.0774155
Service	0.0964	S1	0.041	0.0039524
		S2	0.1202	0.0115873
		S3	0.2257	0.0217575
		S4	0.6131	0.0591028
Environmental and social responsibility	0.0447	ESR1	0.0421	0.0018819
		ESR2	0.1576	0.0070447
		ESR3	0.255	0.0113985
		ESR4	0.5453	0.0243749
Cost and Finance	0.2561	CF1	0.07676	0.0196582
		CF2	0.25003	0.0640327
		CF3	0.67321	0.1724091

7) Calculate the consistency ratio (CR) by using the consistency index (CI) and random consistency index for all comparison matrices of criteria and sub-criteria to check the consistency for subjective judgement of decision makers.
8) At the next level of the hybrid approach, the decision makers evaluate each supplier and give a score to them. For example, decision maker 1 evaluates supplier 1 as a *Good* supplier in *Management Capability* as shown in Table 9. All decision makers give scores based on their perception of thinking for criteria for every supplier. The same Likert scale has been used to reduce variability in the results.

Table 9. Alternative supplier evaluations of all decision makers' preference

Decision Maker 1																						
Suppliers	C1	C2	C3	C4	C5	C6	CF1	CF2	CF3	S1	S2	S3	S4	QR1	QR2	QR3	QR4	QR5	ESR1	ESR2	ESR3	ESR4
Supplier 1	9	3	4	7	9	8	7	8	9	9	7	4	5	6	7	8	9	8	9	4	5	6
Supplier 2	6	6	5	5	9	5	5	6	7	8	9	7	8	4	5	6	7	8	9	8	7	4
Supplier 3	7	7	8	9	5	9	6	7	4	5	6	7	8	9	9	5	8	5	6	7	8	9
Supplier 4	7	9	4	6	7	6	4	5	6	7	8	9	8	9	8	5	6	7	8	9	8	8
Supplier 5	9	4	6	7	4	7	9	8	7	6	5	4	3	2	9	8	7	6	5	4	8	9
Decision Maker 2																						
Suppliers	C1	C2	C3	C4	C5	C6	CF1	CF2	CF3	S1	S2	S3	S4	QR1	QR2	QR3	QR4	QR5	ESR1	ESR2	ESR3	ESR4
Supplier 1	7	8	5	6	7	8	9	7	6	4	5	6	7	8	9	5	6	8	6	7	8	9
Supplier 2	8	6	9	8	5	6	7	6	7	8	9	8	6	9	8	7	7	8	4	2	5	7
Supplier 3	5	7	2	4	4	9	8	7	9	8	7	9	8	9	8	3	5	5	6	7	6	9
Supplier 4	8	8	9	7	8	6	7	8	5	6	8	9	5	7	8	9	7	8	9	6	8	7
Supplier 5	9	8	7	6	8	7	9	9	7	8	5	4	3	7	8	8	7	6	5	4	3	8
Decision Maker 3																						
Suppliers	C1	C2	C3	C4	C5	C6	CF1	CF2	CF3	S1	S2	S3	S4	QR1	QR2	QR3	QR4	QR5	ESR1	ESR2	ESR3	ESR4
Supplier 1	7	3	4	8	9	8	8	5	9	7	7	6	9	6	9	7	5	8	9	7	5	6
Supplier 2	9	8	9	9	7	8	8	9	6	8	9	7	8	7	5	5	5	6	9	8	8	4
Supplier 3	8	7	8	7	5	9	8	5	7	6	6	7	8	9	2	8	4	5	6	7	8	9
Supplier 4	7	6	4	6	8	6	8	5	6	7	7	5	7	5	8	6	8	7	4	5	6	3
Supplier 5	5	8	6	5	7	8	6	5	8	9	7	6	5	8	7	4	6	8	6	7	8	7

9) The geometric mean is used to get the reciprocal matrix for paired comparison of all parameters for the decision makers' preferences shown in Table 10.

Table 10. Common reciprocal matrix of each parameter

Suppliers	C1	C2	C3	C4	C5	C6	CF1	CF2	CF3	S1	S2	S3	S4	QR1	QR2	QR3	QR4	QR5	ESR1	ESR2	ESR3	ESR4
Supplier 1	7.612	4.160	4.309	6.952	8.277	8.000	7.958	6.542	7.862	6.316	6.257	5.241	6.804	6.604	8.277	6.542	6.463	8.000	7.862	5.809	5.848	6.868
Supplier 2	7.560	6.604	7.399	7.114	6.804	6.214	6.542	6.868	6.649	8.000	9.000	7.319	7.268	6.316	5.848	5.944	6.257	7.268	6.868	5.040	6.542	4.820
Supplier 3	6.542	7.000	5.040	6.316	4.642	9.000	7.268	6.257	6.316	6.214	6.316	7.612	8.000	9.000	5.241	4.932	5.429	5.000	6.000	7.000	7.268	9.000
Supplier 4	7.319	7.560	5.241	6.316	7.652	6.000	6.073	5.848	5.646	6.649	7.652	7.399	6.542	6.804	8.000	6.463	6.952	7.319	6.604	6.463	7.268	5.518
Supplier 5	7.399	6.350	6.316	5.944	6.073	7.319	7.862	7.114	7.319	7.560	5.593	4.579	3.557	4.820	7.958	6.350	6.649	6.604	5.313	4.820	5.769	7.958

10) A normalized decision matrix (Table 11) is generated for all criteria by using Equation (5). In Table 11, the last row shows the global weightage obtained for AHP algorithm.

Table 11. Normalized decision matrix

Suppliers	C1	C2	C3	C4	C5	C6	CF1	CF2	CF3	S1	S2	S3	S4	QR1	QR2	QR3	QR4	QR5	ESR1	ESR2	ESR3	ESR4
Supplier 1	0.467	0.289	0.334	0.475	0.544	0.484	0.496	0.447	0.517	0.404	0.396	0.358	0.460	0.432	0.516	0.482	0.454	0.517	0.534	0.441	0.398	0.439
Supplier 2	0.463	0.459	0.574	0.486	0.447	0.376	0.408	0.470	0.437	0.512	0.569	0.499	0.492	0.413	0.364	0.438	0.439	0.470	0.466	0.383	0.445	0.308
Supplier 3	0.401	0.486	0.391	0.432	0.305	0.545	0.453	0.428	0.415	0.398	0.400	0.519	0.541	0.588	0.327	0.363	0.381	0.323	0.407	0.532	0.495	0.575
Supplier 4	0.449	0.525	0.407	0.432	0.503	0.363	0.378	0.400	0.371	0.426	0.484	0.505	0.443	0.445	0.499	0.476	0.488	0.473	0.448	0.491	0.495	0.352
Supplier 5	0.453	0.441	0.490	0.406	0.399	0.443	0.490	0.486	0.481	0.484	0.354	0.313	0.241	0.315	0.496	0.467	0.467	0.427	0.361	0.366	0.393	0.508
Weights	0.013	0.026	0.047	0.068	0.108	0.186	0.005	0.005	0.024	0.035	0.077	0.004	0.012	0.022	0.059	0.002	0.007	0.011	0.024	0.020	0.064	0.172

11) After getting the normalized decision matrix, the next step is to calculate the weighted normalized decision matrix (Table 12) by using the global weighting obtained from AHP.

Table 12. Weighted normalized decision matrix

Suppliers	C1	C2	C3	C4	C5	C6	CF1	CF2	CF3	S1	S2	S3	S4	QR1	QR2	QR3	QR4	QR5	ESR1	ESR2	ESR3	ESR4
Supplier 1	0.006	0.008	0.016	0.032	0.059	0.090	0.003	0.002	0.012	0.014	0.031	0.001	0.005	0.009	0.030	0.001	0.003	0.006	0.013	0.009	0.025	0.076
Supplier 2	0.006	0.012	0.027	0.033	0.048	0.070	0.002	0.002	0.010	0.018	0.044	0.002	0.006	0.009	0.022	0.001	0.003	0.005	0.011	0.008	0.029	0.053
Supplier 3	0.005	0.013	0.018	0.029	0.033	0.101	0.002	0.002	0.010	0.014	0.031	0.002	0.006	0.013	0.019	0.001	0.003	0.004	0.010	0.010	0.032	0.099
Supplier 4	0.006	0.014	0.019	0.029	0.054	0.068	0.002	0.002	0.009	0.015	0.037	0.002	0.005	0.010	0.029	0.001	0.003	0.005	0.011	0.010	0.032	0.061
Supplier 5	0.006	0.012	0.023	0.028	0.043	0.082	0.003	0.003	0.012	0.017	0.027	0.001	0.003	0.007	0.029	0.001	0.003	0.005	0.009	0.007	0.025	0.088

12) Find the positive ideal solution and negative ideal solution (Table 13) of the weighted normalized decision matrix for all parameters by using Equation (8).

Table 13. Positive and Negative Ideal Solutions

R+	0.006	0.014	0.027	0.033	0.059	0.101	0.003	0.003	0.012	0.018	0.044	0.002	0.006	0.013	0.030	0.001	0.003	0.006	0.013	0.010	0.032	0.099
R-	0.005	0.008	0.016	0.028	0.033	0.068	0.002	0.002	0.009	0.014	0.027	0.001	0.003	0.007	0.019	0.001	0.003	0.004	0.009	0.007	0.025	0.053

13) Calculate the distance between each criterion of the weighted normalized decision matrix with respect to positive ideal solution and negative ideal solution as shown in Equation (9) and (10).
14) Compute the closeness coefficients for each supplier by using the distance between the positive ideal solution and the negative ideal solution as shown in Equation 11. Evaluation results are shown in Table 14.

Table 14. Closeness coefficients of suppliers

Suppliers	d+	d-	CC(i)
Supplier 1	0.001091	0.001886	**0.6336**
Supplier 2	0.003333	0.000752	**0.184**
Supplier 3	0.001085	0.003411	**0.7586**
Supplier 4	0.002786	0.000844	**0.2324**
Supplier 5	0.001184	0.001704	**0.59**

The closeness coefficients can be used as the supplier performance score for the order allocation process. It can be used to determine the performance level by considering all qualitative criteria into different evaluations shown in Table 3. Since, the closeness coefficients are ranked from the uppermost value to the lowermost, supplier 3 falls into the “Acceptable” evaluation with a higher score. The performance of Supplier 4 is determined to be a “Recommend with high risk” evaluation.

5. Conclusion and Future Work

In this research, a novel hybrid approach of Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are used to formulate the qualitative approach for the supplier assessment. With the AHP method, a weightage for each criterion is computed using linguistic variables for qualitative criteria. The closeness coefficients of the TOPSIS algorithm were considered as the supplier performance score. The closeness coefficients of all suppliers have been used as the supplier performance scores. For the supplier selection process, a supplier with a higher closeness coefficient is selected first. But in the Supplier Assessment, we can use this to divide suppliers into different priorities. In this paper, a case study of a manufacturing firm with five suppliers was considered.

There are several directions for the future work in the supplier assessment problem. The more qualitative criteria could be taken into consideration for the assessment problem as in the future research. Research can also be done in the supplier assessment problem by using fuzzy numbers which could help to decrease the uncertainty in the decision making. This paper has considered the qualitative approach. The future work may be performed considering the multi objective integer linear programming (MOILP) for the order allocation program by considering the supplier performance score as one of the objectives for optimization.

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